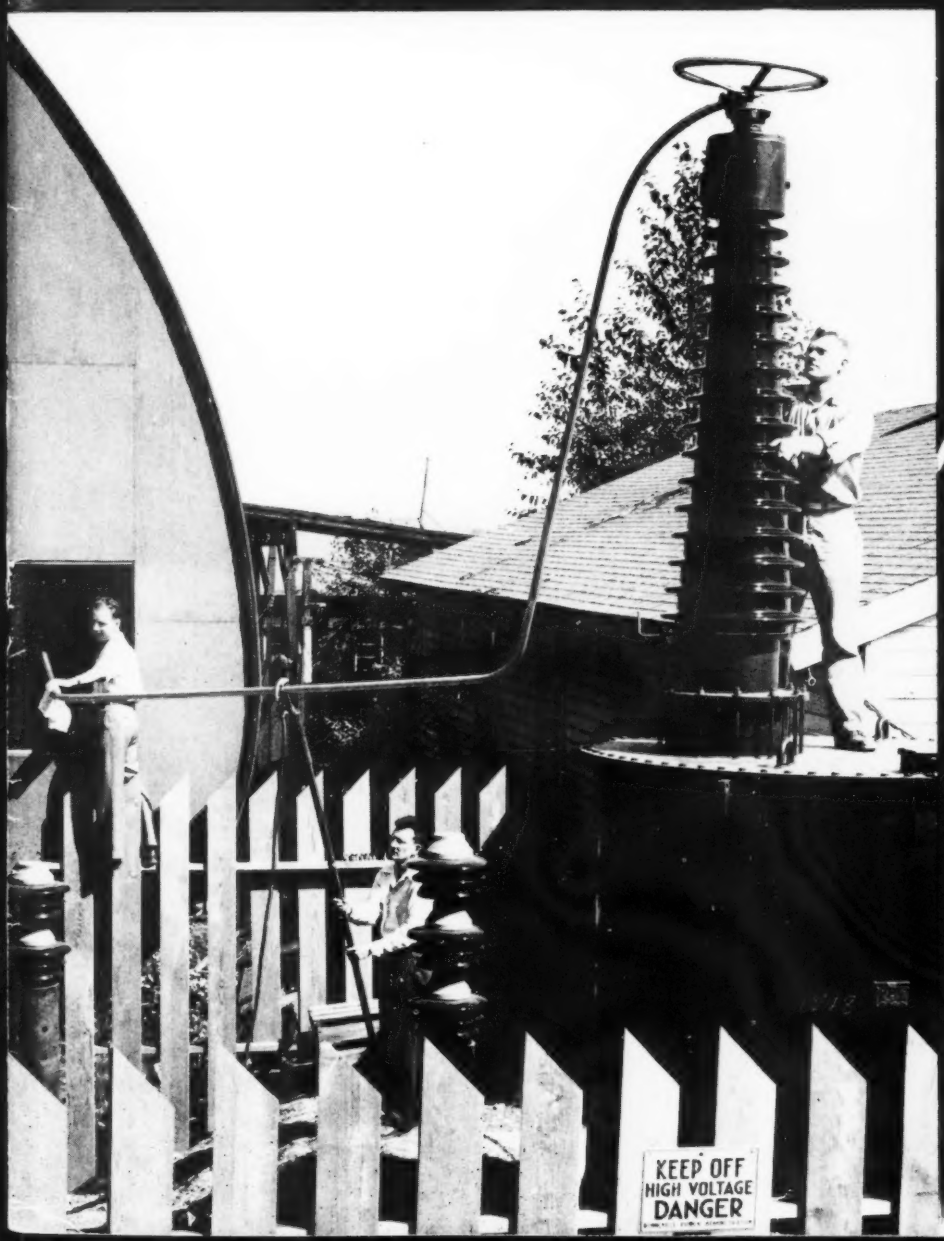
The TREND

IN ENGINEERING

at the University of Washington



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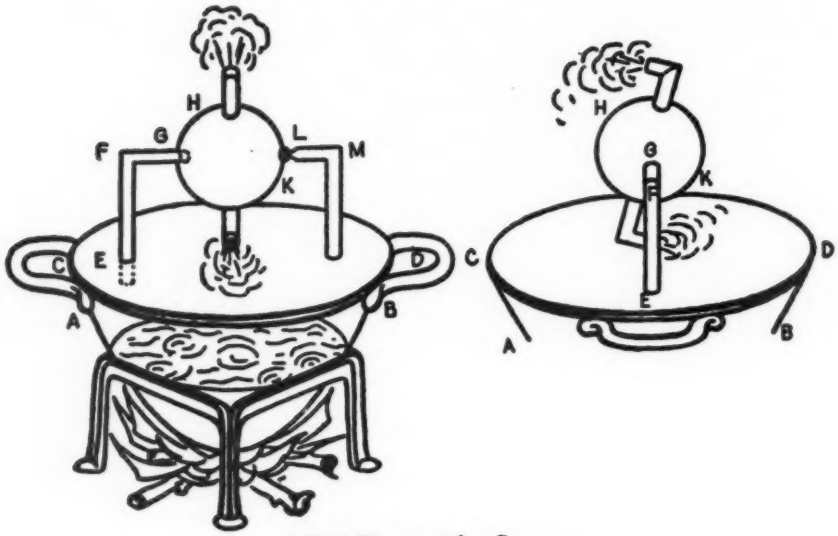
- Steam Plants and the Northwest Power Shortage
- Performance of Vapor-Lift Pump Under Vacuum
- Absorption Tower Design Study Completed
- An Oscillograph for Transient Recording
- Heat-Pump Evaporator Heating: Its Effects on Heat Transfer
- Gold Mirrors Produced
- Chromatographic Study of Sulfite Waste Liquor Sugars
- Power-Line Radio Interference Tests in Wind Tunnel

October, 1951

VOL. 3, No. 4



A Ball Rotated by Steam

FIG. 1. A PRIMITIVE PROGENITOR OF THE STEAM TURBINE
From SOURCE BOOK IN GREEK SCIENCE *by Cohen and Drabkin*
Courtesy McGraw-Hill Book Co.

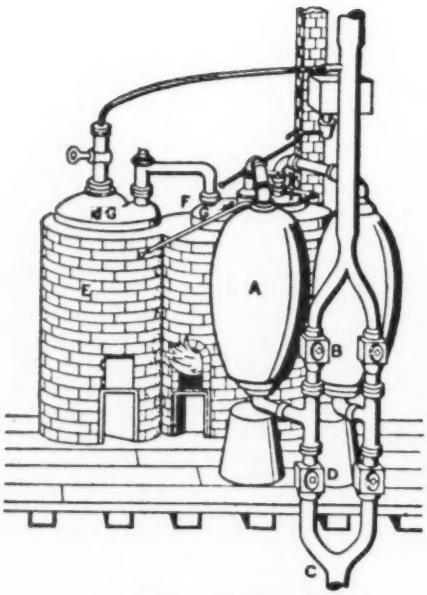


FIG. 2. SAVERY STEAM ENGINE
Courtesy ENCYCLOPEDIA BRITANNICA

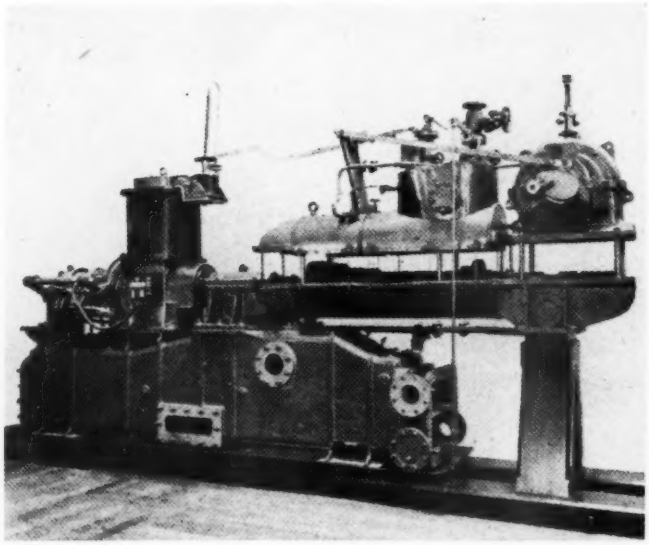


FIG. 3. PARSONS TURBO-GENERATOR WITH UPPER TURBINE CASING LIFTED TO SHOW ROTOR
From the original in THE SCIENCE MUSEUM, London

Steam Power Through the Ages

FIG. 1. A BALL ROTATED BY STEAM—*Philo of Byzantium, 200 (?) B.C.*

PLACE A CAULDRON over a fire: a ball shall revolve on a pivot. A fire is lighted under a cauldron, *AB*, containing water and covered at the mouth by the lid *CD:* with this the bent tube *EFG* communicates, the extremity of the tube being fitted into a hollow ball, *HK*. Opposite to the extremity *G* place a pivot, *LM*, resting on the lid *CD*; and let the ball contain two bent pipes, communicating with it at the opposite extremities of a diameter, and bent in opposite directions, the bends being at right angles and across the lines *FG, LM*. As the cauldron gets hot it will be found that the steam, entering the ball through *EFG*, passes out through the bent tubes towards the lid, and causes the ball to revolve."

—*Pneumatica*, Philo of Byzantium. Translation of J. G. Greenwood. From SOURCE BOOK IN GREEK SCIENCE by Cohen and Drabkin, pp. 254-55. Copyright, 1948, by McGraw-Hill Book Company.

FIG. 2. STEAM ENGINE—*Thomas Savery, 1698*

EARLIEST STEAM ENGINE to take a practical form and find employment in industry was that of Thomas Savery, who in 1698 obtained a patent for a water-raising engine. . . . Steam is admitted to one of the oval vessels *A*, displacing water, which it drives up through the check-valve *B*. When the vessel *A* is emptied of water the supply of steam is stopped, and the steam already there is condensed by allowing a jet of cold water from a cistern above to stream over the outer surface of the vessel. This produces a vacuum and causes water to be sucked up through the pipe *C* and the valve *D*. Meanwhile steam has been displacing water from the other vessel, and is ready to be condensed there. The valves *B* and *D* open only upward. The supplementary boiler and furnace *E* are for feeding water to the main boiler; *E* is filled while cold and a fire is lighted under it; it then forces a supply of feeding-water into the main boiler *F*. The gauge cocks *G, G* are an interesting detail. . . . Pressures as high as 8 or 10 atmospheres were employed—and that, too, without a safety-valve. . . . The waste of fuel was enormous . . . the consumption of coal was, in proportion to the work done, some twenty times greater than in a modern engine."

—ENCYCLOPEDIA BRITANNICA, 1945 printing, page 352.

FIG. 3. STEAM TURBO-GENERATOR—*Sir Charles Parsons, 1902*

IN 1884 PARSONS INTRODUCED his compound steam turbine, but "for some years it was made in small sizes only and the steam was discharged to the atmosphere without condensation. In 1891 it was first fitted with a condenser, and it then began to be used in electric supply stations. . . . In his invention of the 'compound' turbine [Parsons] divided the whole expansion of the steam into a great number of successive and separate steps, and thereby limited the velocity acquired at each step to such an extent as to make it comparatively easy to extract the greater part of the kinetic energy as work done upon the moving blades, without making the velocity of these blades inconveniently high. . . . The guide blades, which form the jets, are distributed round the whole circumference of the revolving wheel. . . . The steam streams from end to end of the turbine through an annular space between a revolving drum and the casing which surrounds it. Parallel rings of fixed guide blades project inwards from the casing at suitable distances, and between these are rings of moving blades which project outwards from the drum and revolve with it. At each step in the expansion the steam streams through a ring of fixed guide blades, and the streams so formed impinge on the next ring of moving blades, and so on."

—ENCYCLOPEDIA BRITANNICA, 1945 printing, page 355.

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;
(2) to undertake extended research and to publish reports on engineering and scientific problems;
(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

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2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
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October, 1951

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Vol. 3 No. 4

Published quarterly in January, April, July, and October, by the Engineering Experiment Station at the University of Washington to reflect the current highlights of its accomplishments and to report progress in its program of investigation and research.

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127 More Hall
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Seattle 5, Washington

Entered as second-class matter March 7, 1949, at the post office at Seattle, Washington, under the act of August 24, 1912.

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COVER

The photograph shows the transformer used to investigate the effects of wind velocity on radio noise emanating from high-voltage transmission-line conductors, a project sponsored jointly by the Bonneville Power Administration and the University of Washington. Seen in the picture are E. P. Single, BPA supervisor of the project, on top of the transformer; R. E. McHugh, U. of W. wind-tunnel operator, grounding the conductor; and J. E. Neuschwander (BPA), cleaning the bus, which at peak load carries 175,000 volts. (See page 27.)

Interior View of Sewaren Steam Plant at Newark, New Jersey

Courtesy Public Service Electric and Gas Co., New Jersey

STEAM PLANTS AND THE NORTHWEST POWER SHORTAGE

FLOYD D. ROBBINS

Assistant Professor of Electrical Engineering

PART I: THE STEAM PLANT IN THE SOLUTION OF THE POWER PROBLEM

F. D. Robbins

The Pacific Northwest is now suffering from an acute power shortage. The Northwest Power Pool which supplies power to this region has at the present time little or no reserve capacity, so that, even with stream flow exceeding that normally expected, at times it is necessary to drop some loads, such as customers with interruptible contracts, and to decrease voltage and frequency to maintain stability of the system. In addition, a number of large potential users of power are waiting to sign contracts when and if additional power becomes available.

Present plans call for the construction of additional hydroelectric plants mostly on the Columbia River and its tributaries, but even if the proposal is kept on schedule or even accelerated, the power shortage will likely continue at least into 1954.[1,2]

A graphic picture of this situation is given in Fig. 1. These curves were plotted from data completed after several years of research on the subject at the University of Washington.[3] The curve marked (1) is a plot of the total installed and planned generating capacity in the area of the Northwest Power Pool, including the states of Washington, Oregon, Idaho, Montana, and part of Utah. Curve (1) takes into account every known existing installation and planned power project in this area down to and including those of 0.1 megawatt (100 kilowatts) capacity, regardless of type of ownership. Values shown are name-plate ratings in megawatts.

Power-load prediction curves, determined by several independent methods, are shown in Fig. 1 as curves (2) and (3).[2] Curve (2) shows the minimum amount of installed capacity to just meet predicted loads, with no margin and providing there is no change in rate of load increase. Curve (3) shows the basic capacity needed to serve the predicted load plus a small reserve. Observation of these curves shows that there will not be enough installed capacity to meet even the predicted load until late in 1954, and there will be no appreciable margin until 1957. By the end of 1951 the Pacific Northwest will have a minimum power shortage of 815 megawatts and a possible power shortage of 2,425 megawatts.[4] The average power urgently needed to meet predicted loads with a small margin for low water is 1,620 megawatts. Washington, with 60 per cent of the installed capacity of the pool, will have a critical power shortage of 972 megawatts. Again it must be emphasized that these figures are based on the condition that present projects will be completed as planned. The need, therefore, is urgent for additional generating capacity that can be constructed quickly and easily, and can be built and operated economically.

General Advantages of the Steam Plant

The steam plant has a very definite advantage in ease and speed of construction. The design of modern stations is well known and quite standardized so that no serious design problems are involved. The fact that such plants are logically located near shipping centers, and consequently near load centers, facilitates construction. A modern steam station of the size to be considered in this report can be built and have the first generating unit on the line supplying power in about one and one-half years. For example, at the Sewaren Station of the Public Service Electric and Gas Co. of New Jersey, excavation was begun in January, 1947, and the first 100-megawatt (100,000 kilowatt) unit was in commercial

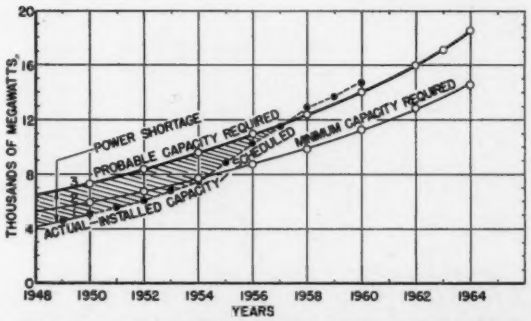


FIG. 1. PREDICTED LOAD AND INSTALLATION CURVES FOR THE PACIFIC NORTHWEST

operation in November, 1948, and the second unit, December 1, 1948.[5]

In the event of a national emergency, construction could be expedited. Hydroelectric plants, on the contrary, take five years or longer to build, with little possibility of expediting the construction.

Other aspects of using modern steam plants for relief of the Northwest power shortage will be investigated, including the important factor of economics. Before proceeding to the economic analysis, it is well to clarify the position of the steam plant in the integrated power system of the Pacific Northwest, and to review briefly the basic principles in such a system.

The Northwest Integrated Power System

The state of Washington has at present a total installed generating capacity of 3,482 megawatts.[4] Of this total, approximately 244 megawatts or about 7 per cent is in steam-electric generating stations, and the remainder is hydroelectric. The value of 3,482 megawatts represents about 60 per cent of the generating capacity of the Northwest Power Pool, thus making Washington the most important part of the power system. Planned installations will generally follow this same ratio since the Columbia River, on which most of the major projects are located, is chiefly in Washington.

The installed capacity of hydroelectric projects is based on the average or mean flow of water in the stream involved. If the flow of water were steady throughout the year and from year to year, the design and operation of a hydroelectric plant would be much simplified. However, the run off and flow in rivers generally deviate from the means from year to year and from season to season within the year. Generally speaking, there will be one period in the year when natural storage, run off, and reservoir storage will not provide sufficient water to operate the turbines, and consequently peaking capacity will be insufficient. Manifestly this low-water period will be worse in some years than in others. In the Pacific Northwest low water usually occurs when the system peak is highest, that is, in December and January. Drawdown of the reservoirs to meet this peaking leaves the system with insufficient stored water to meet the energy requirements of the system. Another peculiarity of the hydro system is the fact that during flood periods the back-water levels rise, the net head is thereby cut down, and the plant loses some of its peaking ability. For example, the Rock Island plant on the Columbia River was shut down during the extreme high water of the flood in the spring of 1949. Obviously the steam plant which is independent of flood or low-water conditions can furnish a dependable peaking capacity during flood and a dependable energy supply during low water, which would allow the hydro plants to save sufficient water to carry the peak load. The steam plant is therefore a highly desirable source of power in a basic hydro system.

Hydroelectric projects also, by their very nature, are usually situated far removed from the load, necessitating long transmission lines over mountainous terrain, and thus increasing the danger of power failure. The steam plant, which is inherently situated close to the load and transportation centers, can serve equally well as a breakdown source of power supply.

These facts indicate that from an operating standpoint alone a certain per cent of steam generation is desirable on an integrated network if the maximum benefit is to be derived from the hydro portion of the system. It is the purpose of this report to show that a steam plant, under modern conditions, can also be compared favorably with the hydro plant on an economic basis.

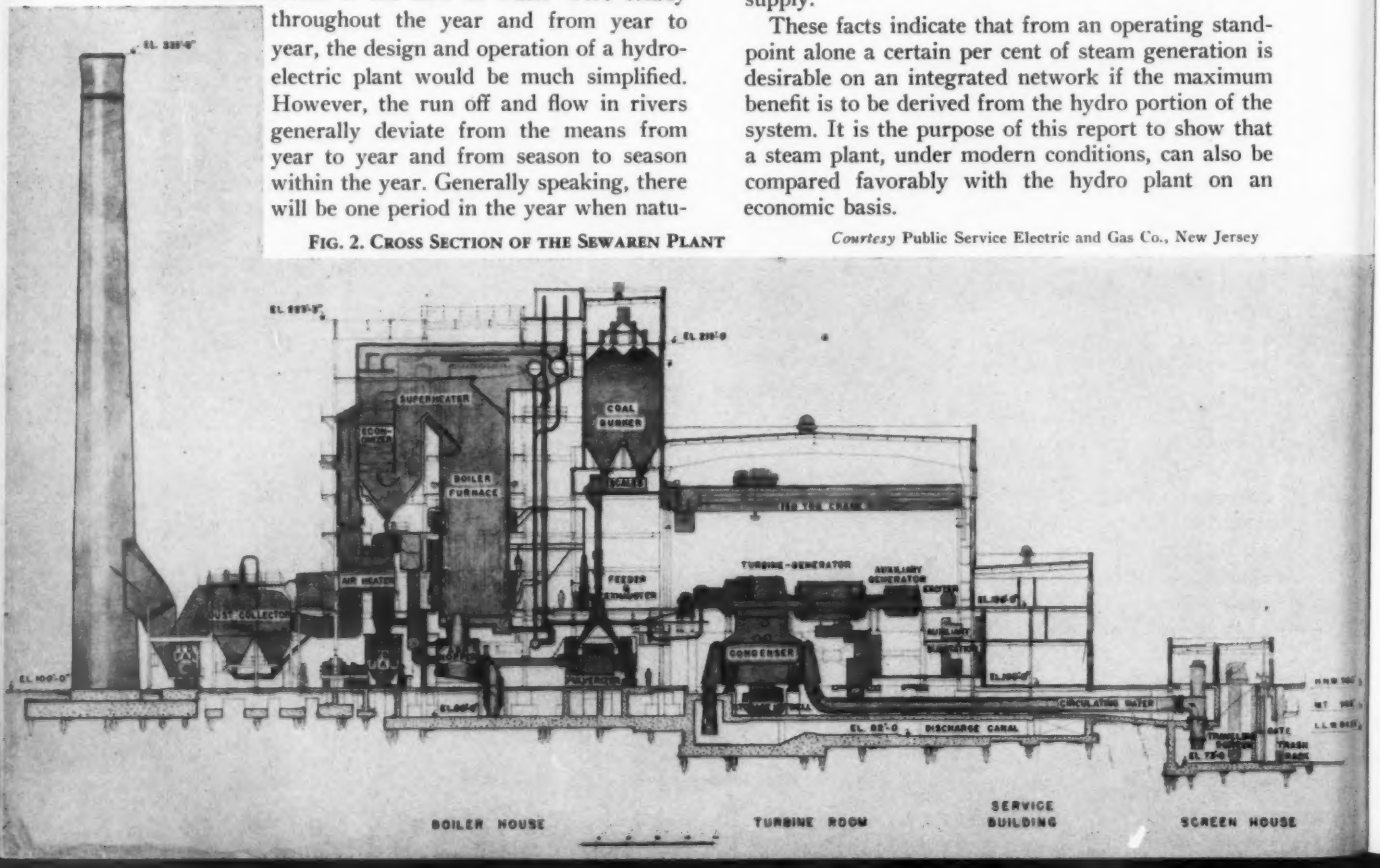


FIG. 2. CROSS SECTION OF THE SEWAREN PLANT *Courtesy* Public Service Electric and Gas Co., New Jersey

Steam Power-Plant Operation Costs

The steam plant under consideration is assumed to be of sufficient size and construction to have maximum thermal efficiency and minimum cost. The station will, therefore, incorporate all modern steam-station design standards and will be comparable to the most modern and efficient steam stations in the United States. To test the validity and reasonableness of the conclusions, one of the latest and most efficient steam stations in the United States has been used as a standard of comparison. This station, called Sewaren, was constructed in 1948-50 by the Public Service Electric and Gas Company of New Jersey.[6,7] An interior view of this station is shown in the frontispiece, and a cross section in Fig. 2.

The following economic analysis, presented by the author to the Federal Power Commission in Washington, D.C., incident to the hearing on the feasibility of the Cowlitz Project,[8] is for a 300-megawatt steam plant on tidewater near Tacoma, Washington, as an alternate project for a 345-megawatt hydroelectric project on the Cowlitz River in Lewis County, Washington. In this analysis the 300-megawatt steam station would be the first plant of the required aggregate capacity of 900 megawatts (900,000 kilowatts), which was previously mentioned as meeting approximately the estimated 1951 shortage in the state of Washington. The calculations will apply equally well to a second 300-megawatt station located on the Columbia River near Vancouver, Washington. They will also be applicable with a small change in fuel cost to a third plant on the Columbia River near Richland, Washington.

The steam station to be analyzed will have the following general specifications:

1. Type of construction: semi-outdoor
2. Thermal efficiency: 11,000 Btu per kilowatt hour, or 31 per cent
3. Location: on tidewater near Tacoma, Washington
4. Size of units: 100 megawatts
5. Number of units: 3
   Plant capacity: 300 megawatts (300,000 kilowatts)
6. Fuel: either coal or oil
7. Boilers: one per turbine, 1500 psi, 1050° F temperature, with water walls, superheaters, economizer and air heater
8. Turbines: 3,600 rpm, condensing tandem compound triple flow, extraction at 8 points, regenerative cycle
9. Generators: 3 phase, 60 cycles, 13.8 kv, hydrogen-cooled, rated at 100,000 kw at unity power factor
10. Cost of station: $150 per kilowatt, total, $45,000,000

The proposed plant was to be located at tidewater near Tacoma to provide ample cooling water, tanker shipment of oil, railway or truck shipment of coal, and proximity to a load center. The cross section of the Sewaren Station, shown in Fig. 2, is an example of such a plant.

Size of units was chosen after exhaustive study of the relative characteristics of 245 typical steam plants throughout the United States as published by the Federal Power Commission.[9,10,11] Consideration was also given to the Sixth Steam Station Cost Survey published by *Electrical World*.[12] Average thermal efficiencies were computed for various size categories. The results are shown on the typical curve, Fig. 3. Because of a distinct hump in the curve in the 75-100 megawatt class, the upper value of this classification was chosen.

Cost per kilowatt was selected as $150 as representing the lowest published cost per kilowatt of the most modern stations in the United States adjusted by price index to values in Tacoma as of November, 1950.[11,12] This cost of $150 is considered to be on the high side since stations are now under construction in which the cost cuts, due to modern ideas and design improvements in construction methods, have more than offset the rising price index.

Price of fuel was selected as the current (November, 1950) price by tanker lot on Puget Sound in the case of oil, and estimated prices in train-load lots for coal. Oil price used was $1.60 per barrel (42 gallons), 150,000 Btu per gallon. The author's estimate of $3.50 per ton in the boiler bunkers was for subbituminous coal, strip mined, 9,000 Btu per pound, in 1,000,000 tons-per-year lots. For comparison a second coal price of $5.20 was also used. This price was estimated by Mr. Holland Houston,[13] August, 1950, and is generally regarded as over-conservative and too high by coal producers and consulting engineers. To facilitate computations and to make it possible to apply this analysis to various unit costs of coal and oil, a family of curves were plotted showing comparative prices of oil against costs of various grades of coal. These curves are shown in Fig. 4.

The economics of the steam plant outlined above were analyzed, using the Federal Power Commission system of division of costs into fixed and variable expenses. Expenses were computed for various annual plant factors for four conditions of ownership and operation as follows:

1. Municipal or state-owned, oil-fired
2. Municipal or state-owned, coal-fired, $3.50 coal
3. Municipal or state-owned, coal-fired, $5.20 coal
4. Private corporation-owned, oil-fired
5. Private corporation-owned, coal-fired, $3.50 coal
6. Private corporation-owned, coal-fired, $5.20 coal

Six curves based on these values are shown in Fig. 5. Tabulated results and details of the calculations will be presented in Part II of this report.

The curves just mentioned very clearly indicate that the steam plant built under present conditions by a private corporation cannot hope to compete with one constructed by the Federal Government, the

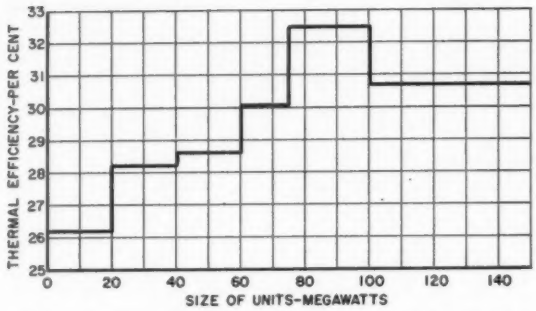


FIG. 3. THERMAL EFFICIENCY RELATED TO SIZE OF UNITS

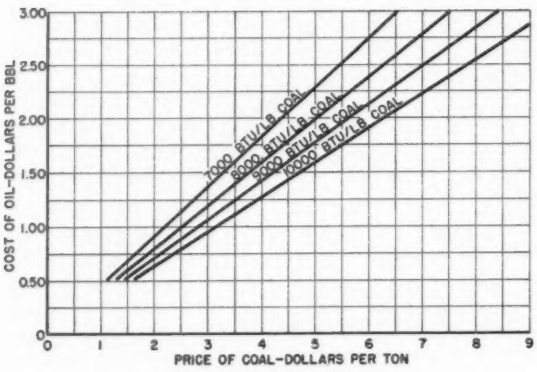


FIG. 4. COMPARATIVE FUEL COSTS
(Oil: 150,000 Btu/gal)

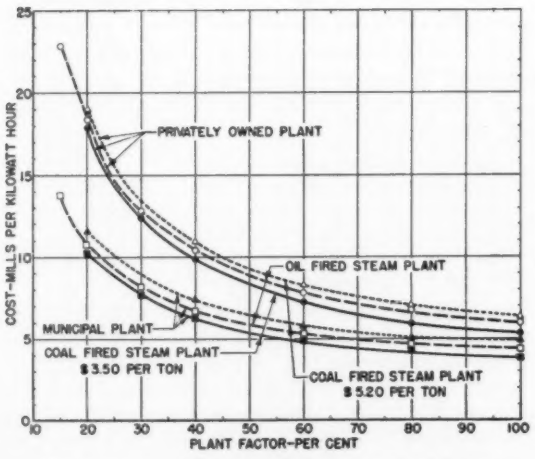


FIG. 5. COMPARATIVE POWER COSTS BY OWNERSHIP

State, a municipality, or other political subdivision. Since the Federal Government is committed to a gigantic hydroelectric development program, steam plants to relieve the power shortage may have to be built by the State or its political subdivisions. Further analysis in this report is therefore based on a particular municipality which has a definite need for more power to serve its residents and has the financial ability to expand its present power system.

As a direct comparison the economics of a municipal-owned hydro plant was worked out. The one chosen was the proposed Cowlitz project in Southwest Washington. The project would have an installed capacity of 345,000 kw, an estimated annual output of 1,378,000,000 kwhr and an estimated construction cost of $136,000,000. These values were taken from a report of the City of Tacoma before the Federal Power Commission.[14] Construction costs on the above basis would be $394 per kilowatt of installed capacity as contrasted with $150 per kilowatt for the comparable steam plant. Cost of producing power at various plant factors is shown in Table I and curve D of Fig. 6.

As a further comparison of the actual costs of hydro power, the value reported by the Department of the Army, Corps of Engineers, in the "308 Report"* may be used as a basis of calculation.[15] The cost of the non-federal hydro production of the Northwest Power Pool was calculated by adjusting all values to 1948 prices by cost indices at the average Power Pool plant factor of 65.4 per cent. Adjusting the costs to current prices, the unit cost of power at the same annual plant factor is 7.11 mills per kilowatt hour. This corresponds to a 100 per cent plant factor cost of 4.54 mills per kilowatt hour. The tabulated values for various plant factors will appear in Part II of this article.

In this same report the predicted value for *cost* of power for future federal projects was determined to be 4.46 mills at the annual plant factor of 75 per cent. The tabulated values for various annual plant factors will also be shown in Part II.

The results of these calculations were consolidated in Table I for convenience of comparison with the values shown graphically in Fig. 6. From these curves it is apparent that the modern steam station can compete on an economic basis with hydro stations at high values of annual plant factor and can actually produce power cheaper at certain low plant factors. As can be seen in Fig. 6, this breaking point occurs at about 60 per cent plant factor even when the higher price of coal is used (curve C).

A still more favorable situation results by a proper combination of steam plants with the Bonneville

* This portion of the report was prepared by the Federal Power Commission.

TABLE I

COST OF POWER UNDER VARIOUS CONDITIONS OF OPERATION AND AT DIFFERENT PLANT FACTORS

Values in Mills per Killowatt Hour

Ownership and Fuel	Annual Plant Factor in Per Cent					
	100	80	60	50.7	40	20
Municipal or State Steam—Oil Fuel...	4.42	4.83	5.51		6.87	10.95
Private Corporation Steam—Oil Fuel...	5.79	6.54	7.79		10.49	17.79
Municipal or State Steam—$3.50 Coal	3.81	4.22	4.90		6.26	10.34
Municipal or State Steam—$5.20 Coal	4.84	5.25	5.93		7.29	11.37
Private Corporation Steam—$3.50 Coal	5.18	5.93	7.18		9.88	17.18
Private Corporation Steam—$5.20 Coal	6.21	6.96	8.21		10.91	18.21
Municipal Owned Hydro—(Cowlitz).	(5.84)	(5.84)	(5.84)	5.84	7.28	14.52
N.W. Power Pool Non-Federal.....	4.54	5.80	7.74		11.60	23.20
Future Federal.....	3.34	4.18	5.57		8.37	16.72

Power Administration hydro system. Surplus energy is available from Bonneville Power Administration 80 per cent of the time at a minimum rate of $17.50 per kilowatt year. By using the steam plants as base load plants during critical water periods and Bonneville Power Administration as a power secondary, an over-all power rate of 3.64 mills per kilowatt hour would result. Details of the calculation will be seen in Part II.

An additional benefit well worth consideration accruing to the state by the construction of one or more steam stations is that a market will be established for low-grade subbituminous coal. This market is now practically non-existent. A 300,000-kw steam station would use approximately 4,320 tons of coal per day of full operation. For 100 per cent plant-factor operation this would represent an annual coal demand for each 300,000-kw plant of approximately 1,576,800 tons. The value of this coal for one plant would be $5,518,800 annually at the $3.50* per ton price. For a price of $5.20* per ton, the value would be $8,199,360 annually.

Any discussion of the power problem in the Northwest should give some consideration to a resource concerned, that has often been overlooked or forgotten, that of salmon fishing. Fishery scientists have pointed out the dangers of building prematurely certain structures which would destroy the salmon runs. The latest development of mechanical fish-passage facilities and of salmon hatcheries is considered incapable of maintaining major runs of salmon in the face of large dam-building projects. Competent fishery men believe that, if the Cowlitz River dams and those on the lower Snake are constructed, the Columbia River salmon will cease to be a major Northwest resource. The strategic location of modern steam-electric plants in the vicinity of Tacoma, Vancouver or Longview, Washington, and near the Hanford atomic plant, would be an important factor in relieving the power shortage at these load centers without requiring installation of structures that would needlessly destroy the salmon.

* In boiler bunkers.

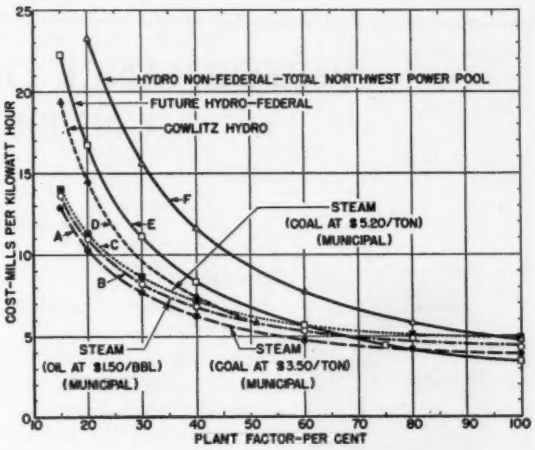


FIG. 6. COMPARATIVE COSTS: STEAM AND HYDRO GENERATING STATIONS

Part II of this report, "Economic Calculations for Steam Power in the Northwest," containing additional detailed data will appear in the January issue of *The Trend.*

REFERENCES CITED

1. "Effect of the Northwest Power Shortage," Bonneville Power Administration, May 12, 1949.
2. ELDRED, WILFRED, "Western Power and Fuel Outlook," *Supplement, Monthly Review,* Federal Reserve Bank of San Francisco, November, 1950.
3. ROBBINS, FLOYD D., "Hydroelectric Power in the Pacific Northwest," Thesis for Degree of Electrical Engineer, University of Washington, 1949.
4. *Ibid.,* Table XVI.
5. "Sewaren Generating Station," Pamphlet P45, Public Service Electric and Gas Co., Newark, N. J., April, 1949.
6. "Sewaren Milepost of Progress," *Power Generation,* Vol. 53, No. 7 (July, 1947).
7. "Sewaren Adopts 1050° Steam," *Electrical World,* Vol. 132, No. 5 (September, 1949).

(Continued on page 32)

PERFORMANCE OF VAPOR-LIFT PUMP UNDER VACUUM*

N. R. MUKHERJEE
Associate in Chemical Engineering

N. R. Mukherjee

Introduction

In the design of continuous distillation plants comprising two or more stills in series, it is frequently necessary to provide means for the transfer of the bottom product from one still to the feed point of the next in the series. When the throughput is comparatively large, as for example, in the petroleum industry, this is best accomplished by means of centrifugal pumps. Cases often arise, however—for example, in pilot plants and in full scale plants in which the materials undergoing treatment are comparatively expensive and the throughput is comparatively low—where the amount to be transferred is of the order of a few hundred gallons per hour or less. The use of centrifugal pumps for such quantities is not satisfactory and an alternative means of pumping becomes necessary. Plunger pumps are frequently used for this purpose, but with most designs vaporization takes place from the surface of the plunger at each stroke as it leaves the stuffing box, resulting in considerable losses. If the liquid being pumped has strong solvent properties it may not be possible to lubricate the pumps satisfactorily, and excessive wear may occur. The latter objection also applies to small rotary positive displacement pumps.

A problem of this nature arose in a plant (B.X. Plastics Ltd. Brantham works, Essex, England) which was being designed for the distillation of turpene hydrocarbon. The bottom product of one distilling column was to be raised to the feed point of the next column. It was thought that a device somewhat similar to the air-lift pump but using vapor instead of compressed air would achieve the desired result. Therefore, this work was undertaken.

*Condensed by the author from the paper by N. R. Mukherjee and H. R. C. Pratt, *Ind. Eng. Chem.*, Sept., 1950, and reprinted by permission of *Industrial and Engineering Chemistry*.

Theory of Operation

No references could be found in the literature dealing specifically with a vapor-lift pump, but the related problem of the air-lift pump has been dealt with in some detail by Swindin.[1]

The most obvious basis of design of a vapor lift is obtained by assuming equality of the weights of liquid in the descending, and of liquid-vapor mixture in the ascending limb. This may be expressed by means of the following equation:

$$\rho_l h_r h_s = \rho_m h_r h_t . \qquad (1)$$

As pointed out by Swindin,[1] however, this equation gives the total height to which a liquid will rise in a tube when no flow is taking place. When flow occurs, the height lifted is less because it is necessary to take into account the following losses of energy:

Entrance loss into downcomer of lifter
Friction loss in downcomer and riser pipes
Exit loss at top of rising main
Loss due to slippage
Loss due to acceleration of liquid in the zone of vapor formation

In the case of the air-lift pump these losses were thoroughly investigated by Swindin,[1] who showed that acceleration can be reduced considerably by means of foot pieces specially designed to prolong the period of aeration. The operation of a vapor lift, although basically the same, differs in that the vapor is not admitted in a predetermined zone. Thus, on passing through the jacketed section the liquid is heated, but owing to the effect of hydrostatic head, vaporization does not necessarily take place in this region. On rising, the liquid reaches a cross section where the total pressure is equal to the vapor pressure and vaporization starts. Between this point and the top of the lift the pressure gradually falls and the quantity of vapor increases. This flashing results in a lowering of the temperature, until at the top it will be the same as that of the saturated liquid under the pressure on the system, providing that a delay in vaporization does not occur, as in the case of the flow of boiling water through orifices. (In an actual case, however, the vapor is slightly superheated.) Theoretically, above the point of initial boiling the condi-

tions must be calculated by an application of the total energy balance equation, which may conveniently be written in the following form:

$$dZ+dE+pdv+vdp+\frac{udu}{g_c}=dQ+dW_{ex.} \quad (2)$$

$$dQ=dE+pdv-dF \quad (3)$$

Assuming that no external work is done by the fluid, and that conditions in the rising pipe above the steam jacket are adiabatic,

$$dZ+vdp+\frac{udu}{g_c}+dF=0 \quad (4)$$

Substituting the value of the friction loss, for flow through a vertical pipe, this becomes

$$dZ+vdp+\frac{udu}{g_c}+\frac{4fu^2dZ}{2g_cD}=0 \quad (5)$$

In Equation 5 the third term refers to the energy loss due to acceleration of the vapor-liquid mixture and the last to the loss due to friction. The energy input to the system which overcomes these losses and at the same time elevates the mixture by the amount given by the first term results from the expansion of the fluid mixture and is given by the second term in this equation. For ease of computation Equation 5 may be expressed in the following form, suitable for stepwise calculation:

$$\frac{(Z_1-Z_2)}{v_{av.}}\left\{1+\frac{4f}{2g_cD}\left(\frac{w}{a}\right)^2 v_{av.}^2\right\}+(p_1-p_2)+\frac{1}{g_c}\left(\frac{w}{a}\right)^2(v_1-v_2)=0 \quad (6)$$

This equation is applied in practice, starting from the point at which vaporization first occurs, which is referred to hereafter as the point of initial boiling (P.I.B.). To find the position of the point of initial boiling the Bernoulli equation may be applied between this point and the level of liquid in the feed vessel. Assuming the velocity in this vessel to be zero, this equation may be written as follows:

$$v(p_o-p_f)+\frac{u_o^2}{2g_c}-Z'+F=0 \quad (7)$$

where Z' is the distance of the point of initial boiling below the static liquid level in the feed vessel and subscripts f and o refer to the feed vessel and the point of initial boiling, respectively. In deriving this equation it is assumed that the specific volumes of the liquid before and after heating are the same. However, in most cases the kinetic energy and the friction loss terms can be neglected, so that the value of Z' is given closely by the difference between the vapor pressure of the heated liquid and the pressure on the system. The method of calculation represented by

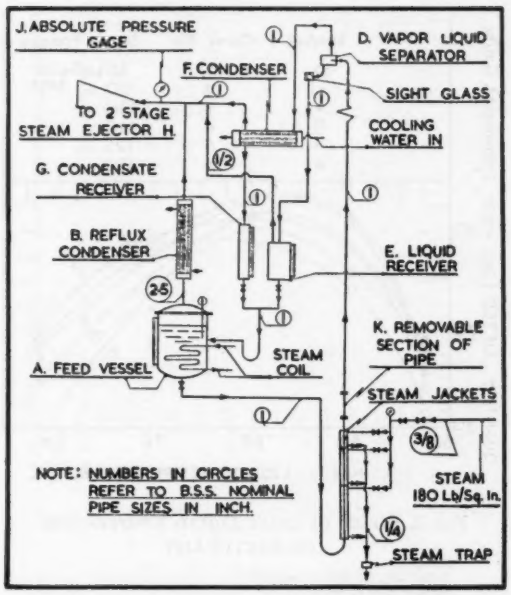


FIG. 1. ARRANGEMENT OF EXPERIMENTAL VAPOR-LIFT INSTALLATION

Equations 5 and 6 is basically the same as that developed by Lewis and Robertson[2] and others for the calculation of circulation rates in water-tube boilers.

Experimental Work

Equipment. The apparatus used is shown in Figure 1. The liquid from the feed vessel *A* passed through the downcomer to the steam-jacketed heating zone of the rising pipe, (34 feet 3 inches) where it was heated by steam. The vapor and liquid mixture rose up the column and separated at *D*, the vapor-liquid separator. A further separation of entrained liquid from vapor was accomplished by a 3-foot vertical section of vapor pipe above the vapor-liquid separator. The separated liquid and the vapor condensate were collected in the respective measuring vessels *E*, *G*, and the cycle was completed by pouring the combined stream of vapor condensate and liquid to the feed vessel *A*. The rising pipe, together with the heating jacket and 3-foot vertical vapor entrainer, was insulated with 1-inch thickness of magnesia-asbestos sectional lagging. For an increase in the rate of vaporization, the inside wall of the riser tube at the heating section should be very rough. Even pointed spikes can be attached to the inside wall of the riser tube to increase roughness.

Material. By-product dipentene (dl-limonene) of specific gravity 0.856 at 15° C/15° C and of boiling temperature range 175° to 182° C at 760 mm. of Hg., was used.

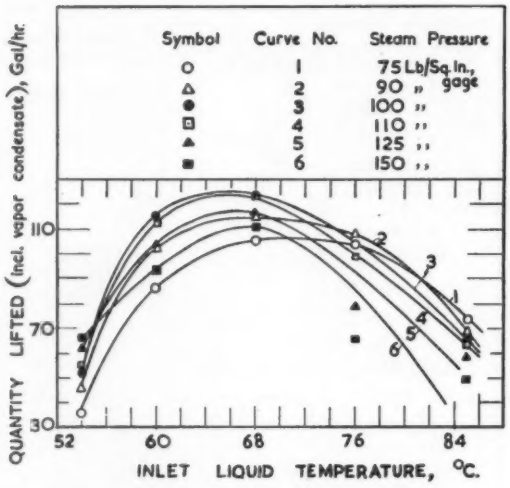


FIG. 2. EFFECT OF INLET LIQUID TEMPERATURE ON RATE OF LIFT

Series C
Total lift, 34 feet 3 inches
Submergence, 44.6%
Absolute pressure on system, 2 inches Hg
Length of steam jacket, 3 feet

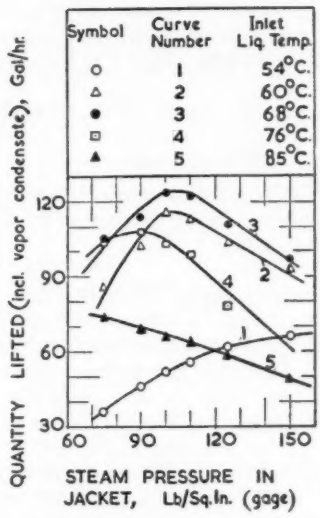


FIG. 3. EFFECT OF JACKET STEAM PRESSURE ON RATE OF LIFT

Series C
Total lift, 34 feet 3 inches
Submergence, 44.6%
Absolute pressure on system, 2 inches Hg
Length of steam jacket, 3 feet

Method of Operation. The ejector pump was first started up and controlled until the desired vacuum was obtained. The water was turned on to the two condensers and the liquid in kettle *A* was brought to the desired temperature as indicated on the dial thermometer. The steam valve leading to the bottom jacket was then opened to bring the lifter into operation quickly, the pressure being allowed to rise to a value 50 to 100% greater than that desired. After a short time, pumping started and 5 to 6 minutes later the steam pressure was lowered to the desired value and maintained constant. After running continuously for 0.5 to 0.75 hour the cocks beneath receivers *E* and *G* were shut and the times required to fill 6 inches of receiver *E* and 3.5 inches of receiver *G* were measured with a stop watch. Under each set of conditions two or three readings were taken and the mean was tabulated.

Results. In a total of 138 runs four series of tests were carried out to investigate the effect of temperature of the liquid entering the lifter, of variation of steam pressure in the jacket, of relative submergence, and of absolute pressure on the system. Data of sample runs showing results of these four tests appear in Figures 2 to 5, respectively. Some of the data obtained with a shorter height of the lifter and with variation of the length of the heating jacket are not shown here.*

*For complete data *vide* original paper.[3]

Examination of Results

Heat Transfer Coefficients. The over-all heat transfer coefficients in the jacketed section of the rising pipe were calculated from the heat inputs and the logarithmic means of the temperature differences at the top and bottom of the jacket. Corrections were not made for the resistance of the condensing steam film and the metal wall, because the accuracy was doubted, owing to the indirect nature of the measurements. In any case, failure to make this correction would result in an error no greater than 10 to 30% in the majority of cases. The results are plotted against the rate of flow in Figure 6.

As in practically all cases vaporization did not occur in the heating section, it was anticipated that the heat transfer coefficients could be correlated by the usual equation for heat transfer to liquids inside pipes under forced convection, as for evaporators operating with high liquid velocities in the tubes.[4] The line shown in Figure 6 for series A to C is represented by the following equation:

$$U = 229u^{0.8} \qquad (8)$$

Assuming the viscosity and thermal conductivity to be the same as for turpentine, the value of the constant in Equation 8, calculated from Colburn's proposed correlation for forced convection,[5] was 72.5. Consequently, the heat transfer coefficients obtained in the present work for series A to C were three times the expected value and were still higher

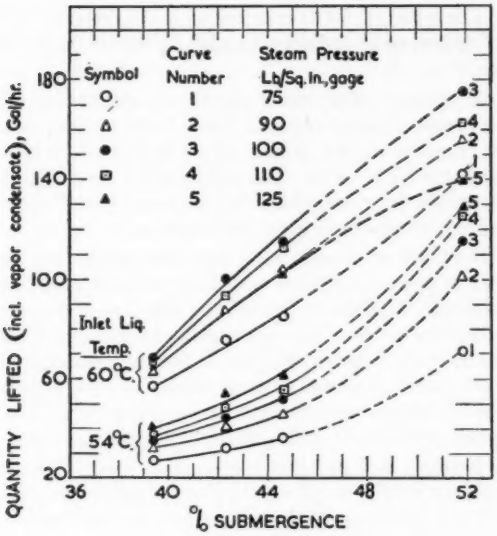


FIG. 4. EFFECT OF SUBMERGENCE ON RATE OF LIFT
Absolute pressure on system, 2 inches Hg
Length of steam jacket, 3 feet

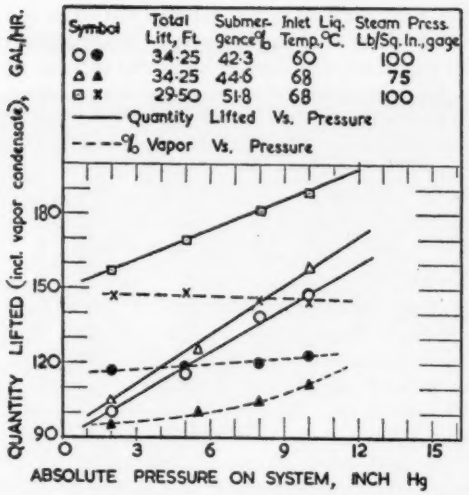


FIG. 5. EFFECT OF ABSOLUTE PRESSURE ON SYSTEM ON RATE OF LIFT

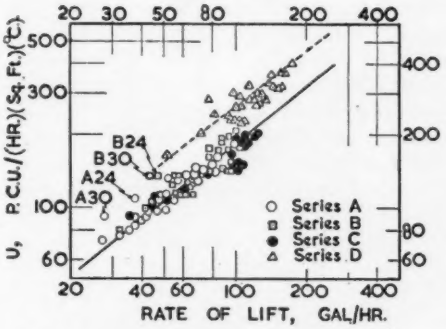


FIG. 6. DERIVED OVER-ALL HEAT TRANSFER COEFFICIENT FOR HEATER JACKET

in the case of series D.* The reason for this discrepancy is discussed in the original paper.[3]

Comparison with Theory. Attempts were made by stepwise application of Equation 6 to calculate the total height to which the liquid would rise in the case of a few typical runs.

Owing to lack of data no correction was made for slippage loss, and the friction factor was assumed to be the same throughout as that calculated for the liquid at the point of initial boiling. This value is almost certainly high but was used merely to illustrate the application of Equation 6. The results of these calculations for three runs are given in Table I.

Runs A7 and A12 are of interest because the amounts lifted were of the same order, although the proportion of vapor formed in the second was almost double that in the first. The effect of friction was very much greater in the case of run A12, owing to the higher velocity at the outlet. This illustrates the reason why in general there are two values of the heat input for any quantity lifted.

Thermal Efficiency of Vapor-Lift Pump. The efficiency of the lift was calculated by comparing the actual energy input in terms of heat added in the jacketed section to the work done in elevating the liquid. This was found to be very low, generally less than 0.1%, although if the heat input for vaporization alone was considered the efficiency was increased.

TABLE I

COMPARISON OF CALCULATED AND ACTUAL LIFTS FOR THREE TYPICAL RUNS
(Submergence: 13.5 feet. Total actual lift: 34.25 feet)

Run No.	Amount Lifted Gal./ Hour	Vapor %	Height to P.I.B., Ft.	Total Calcd. Lift, Ft.	
				Excl. Friction	Incl. Friction
A1	27.7	4.30	12.1	84.9	47.7
A7	57.2	5.25	12.1	56.3	20.6
A12	51.1	10.4	10.3	186.6	34.3

The low efficiency of the lifter would be anticipated from the Carnot principle, because the difference between the temperatures after heating and after expansion is comparatively small. However, the main application of the vapor-lift pump would appear to be the feeding of distillation columns, and an examination of the operating diagram for a typical column

*Designations "Series A, B, C, etc." were used in the original paper[3] for distinguishing the different sets of runs.

shows that this heat is not entirely lost: The feed to the still which is being fed by the vapor lift is partially vaporized and the boil-up of this still can therefore be reduced by an amount corresponding to the vapor entering in the feed, provided that the height of the stripping section is increased slightly. However, if it is necessary to cool the liquid entering the lifter below saturation temperature as in the present work, the sensible heat removed will be lost unless it can be recovered in a heat exchanger.

Discussion

It is apparent from the foregoing results that the mechanism of the vapor-lift pump is very complicated, inasmuch as the rate of lift depends on the balance between the energy input term, $\int v dp$, and the energy losses due to acceleration, slippage, and friction. When the rate of lift is comparatively low and the proportion of vapor small, the effect of increasing the steam pressure and hence the rate of heat transfer is to increase the rate of lift. The increase in lift may sometimes be accompanied by a decrease in the proportion of vapor formed, although the total heat transferred is greater. As the proportion of vapor increases, however, the velocity at the top of the lifter becomes very high and the friction losses increase rapidly, so that the rate of lift reaches a maximum and then decreases as the heat transfer is further increased. Kirschbaum[6] *et al.* obtained a similar result in their experiments with a natural circulation evaporator.

The results of the experiments shown in Figure 5 are of interest because the rate of lift was found to increase considerably with pressure. The conditions under the different pressures are not strictly comparable, because the saturation temperature of the liquid increases with pressure and consequently the relative subcooling of the inlet liquid also increases. The heat transfer coefficient appeared to increase to extremely high values, although the vapor pressure of the heated liquid in all cases was lower than the total pressure (including hydrostatic head) at the top of the heating section. However, at the higher pressures the difference was not great and the results indicate that incipient vaporization in the heating zone must have resulted in a considerable reduction in thickness of the laminar film.

Full-Scale Vapor-Lift Installation

Two full-scale vapor-lift pumps were designed, constructed and operated on the basis of the experimental work at the B. X. Plastics Ltd., Brantham Works, Nr. Manningtree, Essex, England, where the installation proved to be a complete success.

Conclusions

A vapor-lift pump will operate satisfactorily under vacua as low as 2 inches of mercury absolute.

The rate of lift increases with the relative submergence and possibly also with reduction in the net height lifted.

A critical value exists for the steam pressure in the heater jacket and hence for the rate of heat transfer, the rate of lift falling off with higher or lower pressures. This effect is explained by the rapid increase in the energy loss due to friction as the proportion of vapor generated is increased.

Contrary to expectations, the inlet liquid temperature appears to have a profound effect on the performance, as there is a critical value below or above which the rate of lift diminishes. This critical temperature was lower than the saturation temperature corresponding to the pressure on the system. It is not clear whether this effect would occur with lifters operating under comparatively high pressures.

When operating under a pressure of 2 inches of mercury it was found that vapor formation generally did not occur until the liquid had reached a point considerably above the top of the heating zone. This effect is due to the relatively large influence of the hydrostatic head when operating under low pressures and it becomes less as the pressure on the system is increased.

The over-all heat transfer coefficient in the heating zone was found to vary as the 0.8 exponent of the liquid velocity, except for isolated runs in which the heat-transfer rate was so large that vaporization occurred in the jacketed section. Correction was not made for the resistances of the condensing steam film and of the pipe wall, because these were relatively small. The experimental coefficients were about three times those calculated from the usual correlation for heat transfer to a liquid in forced convection in a pipe. This is explained as being due to incipient vaporization occurring in the stagnant liquid film caused by pressure variations resulting from the pulsating nature of the flow. The submergence has practically no effect on the heat transfer coefficient in the heating section, provided the point of initial boiling of the liquid is above the heating zone all the time, i.e., the heating jacket is sufficiently below the static level of the liquid in the lifter tube.

With increasing pressure on the system, the rates of lift were found to increase when the steam pressures and inlet liquid temperatures were maintained constant. The heat transfer coefficients increased very rapidly with pressure, no doubt because of an increase in the degree of incipient vaporization in the heating zone.

In order to control the rate of lift, the control valve should be located in the liquid-inlet line to the lifter and not in the steam-inlet line.

(Continued on page 23)

Absorption Tower Design Study Completed

THE NEED "to clarify some uncertainties concerning the influence of scale and geometry on the design of equipment for absorption of some solutes which react with the solvent," and recognition of "the importance of adequate design to conserve sulfur dioxide and to avoid atmospheric pollution" led to the study on absorption reported in the May issue of *Chemical Engineering Progress,* according to Dr. J. L. McCarthy, one of the authors. The title of the article is "Absorption on a Semi-Works Scale: Absorption of Sulfur Dioxide in Water in a Packed Tower," and the authors are L. A. Lundberg, D. A. Pearson (both research fellows in the Engineering Experiment Station), Frank B. West (Assistant Professor of Chemical Engineering), and Joseph L. McCarthy (Associate Professor of Chemical Engineering). The following summary is reprinted by permission of *Chemical Engineering Progress:**

1. Mass-transfer rates for absorption of sulfur dioxide from air into water have been determined using a semi-works scale packed tower operating in the commercial range of flow rates to absorb nearly completely the influent sulfur dioxide while simultaneously producing 60 to 97% saturated solutions of sulfurous acid.

2. Since phase equilibrium was rather closely approached in the experiments, proper calculation of results required use of the best possible equilibrium data. Therefore, practically all available equilibrium data for the system sulfur dioxide-water within the range of probable absorption conditions have been closely studied, correlated, and smoothed by use of effective mean ionic activity coefficients by a procedure similar to that suggested by Johnstone and Leppla. Relations are recommended which represent the equilibria between sulfur dioxide in a gas phase and in a water solution between 0 and 50° C. and between 0 and 800 mm. Hg. partial pressure of sulfur dioxide.

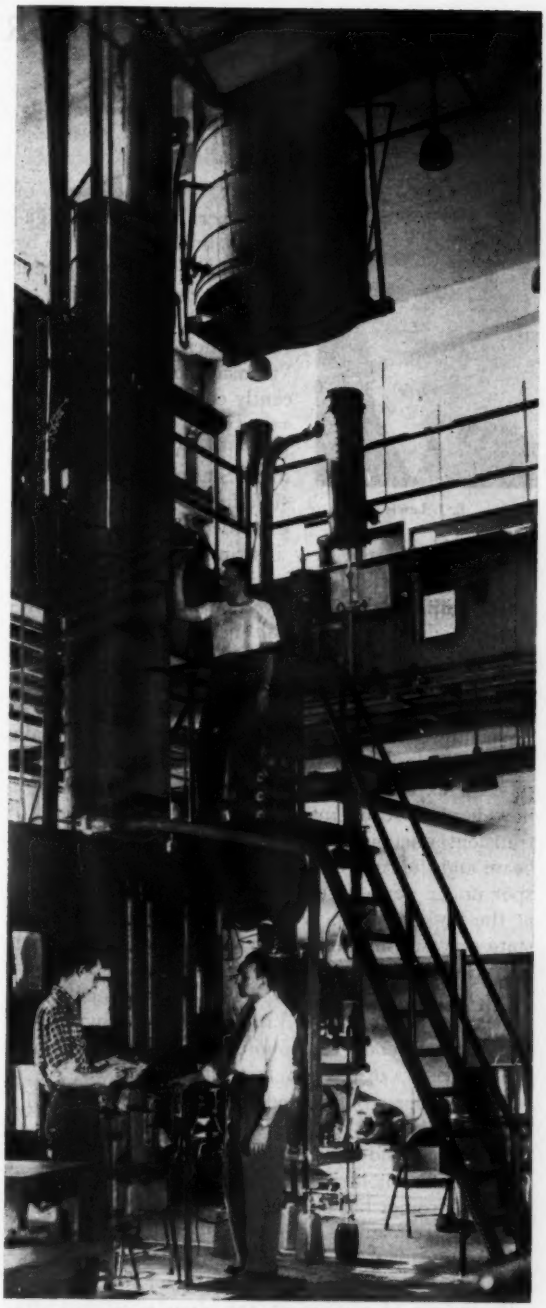
3. Experimental data have been calculated in terms of both the normal and also the pseudo *H.T.U.* The latter values correspond to the pseudoequilibrium and operating lines suggested by Vivian and Whitney for use with systems in which the solute reacts chemically with the solvent at a rate which is inappreciable in the time required to diffuse through the liquid films but which is fast enough to give essentially complete reaction in the bulk of the liquid beyond the film. It is found that the results are correlated considerably better by the experimental pseudo than by the experimental normal values for heights of transfer units.

4. The mass-transfer data now reported appear to be directly and safely applicable to design of appropriate large-scale sulfur dioxide absorption equipment. The present results indicate that data carefully taken on small-scale laboratory equipment appear to be equally reliable provided that end effects are suitably allowed for or eliminated.

Acknowledgments

The authors sincerely appreciate assistance provided by the G. D. Jenssen Co., Inc., in providing absorption equipment, the Great Western Division of the Dow Chemical Company in supplying sulfur dioxide, and the Messrs. P. F. Ticer, Henry Toellner, and John Sundling in constructional and experimental matters.

*For complete article see *Chem. Eng. Prog.*, 47, 257-264 (1951).



Equipment for Study of Sulfur Dioxide Absorption on a Semi-Works Scale

Above: **Lyle Gordon.** ***Below:*** **Stuart Lovell** ***(left)*** **and L. A. Lundberg.**

AN OSCILLOGRAPH FOR TRANSIENT RECORDING

LAUREL J. LEWIS
Associate Professor of Electrical Engineering

WILLIAM F. NIELSEN, III
Research Fellow, Engineering Experiment Station

L. J. Lewis

Very often the scope of an experimental investigation is limited as much by the measuring equipment available as by the skill of the investigator. It is therefore anticipated that a new "transient oscillograph," recently completed at the University of Washington for the Engineering Experiment Station will make possible future investigations of extended interest. Some of the features of the new instrument, shown in Fig. 1, and its possible applications are reviewed here.

The familiar cathode-ray tube performs the function of converting electrical energy into visual light. In early years, photographic films were placed directly in the path of the electron beam in a vacuum to record the motion of the beam as a function of time. Improvements in high-vacuum tubes now make it possible to utilize the light energy from a sealed tube for exposing a photographic film. A distinction, however, must be made between the recording of transient phenomena on a single excursion of the beam and the recording or observation of the moving spot under periodic or steady-state motion. In fact, at the higher speeds where recording in the steady state may still be performed with relative ease, transient recording may be accomplished only with the most careful attention to design requirements. An indication of the design problems will be evident in the relations between photographic and electrical characteristics of the new instrument.

The camera constructed for use with the oscillograph employs an f:3.5 lens with a focal length of 15 centimeters, and utilizes 4- by 5-inch cut film in a standard film holder. This is physically a large lens, although somewhat slower than could be obtained if a miniature camera were used requiring possibly 35-mm film. However, the large film size is a distinct advantage for experimental work, where continued adjustments of equipment are often necessary after each recording. With the film size used, test information can be obtained quickly as soon as the film is developed, without the necessity of enlargement; final prints can also be obtained easily by direct contact printing.

W. F. Nielsen, III

The two critical characteristics of a cathode-ray tube for high-speed transient recording are expressed in terms of the "photographic sensitivity" and the "deflection sensitivity." The first is a measure of the light output that can be obtained, and the second a measure of the voltage necessary at the deflection plates to produce unit deflection of the spot. Unfortunately these are reciprocal quantities; an increase of photographic sensitivity may be achieved by higher beam velocity, but this in turn results in a decreased deflection sensitivity. The present oscillograph uses a type 5RP11 cathode-ray tube, which achieves a high photographic sensitivity and a reasonably high deflection sensitivity by the use of post acceleration; in this tube, final acceleration is applied in three stages from a high-voltage source after the beam is initially deflected. The power supply constructed for use with the oscillograph operates to a maximum of 20,000 volts, for obtaining the necessary spot brightness at the highest operating speeds. The beam must of course remain turned off except during its rapid motion, in order to avoid damage to the phosphorescent coating of the tube face.

Even with post acceleration, the deflection sensitivities available at the higher beam voltages require the use of deflection voltages higher than those employed in a low-voltage instrument. For example, at a beam voltage of 20,000 volts, about 600 volts is required to deflect the spot four inches across the tube face. The development of a special sweep circuit to produce such a voltage, varying linearly, with a minimum sweep time of one microsecond, represents the major achievement of the design. It is evident that, if a sweep voltage were to be produced at a low level and then amplified to the required value, the requirements for an amplifier as to voltage output

and the frequency response would be incompatible. The special feature of this design is an arrangement whereby the necessary sweep voltage is produced directly at the deflection plates without the necessity for further amplification. Provision is included for independent control of the sweep length and selection of any one of eight sweep speeds having durations between 1 and 3,000 microseconds.

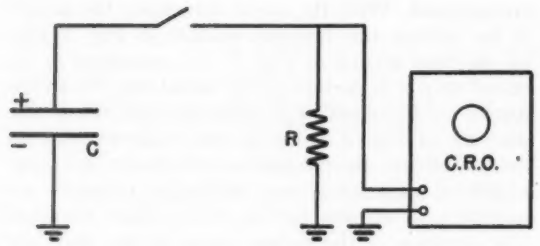
Two general types of application have been contemplated for this instrument, which have dictated the nature of the control and switching arrangements provided. In each case it is anticipated that the signals to be recorded will be of sufficient magnitude so that further amplification will be unnecessary. For that reason no signal amplifier is provided, although one could be used externally if necessary.

The first type of application considered is that such as is required in high-voltage impulse testing. Standard test procedure employs a 1.5–40 wave shape, that is, a surge reaching crest value in 1.5 microseconds and decreasing to half value in 40 microseconds. To illustrate the capabilities of the oscillograph, a test circuit was arranged, which is simply represented by Fig. 2. The closing of a switch connects a charged condenser to a resistor, across which the voltage is recorded by the oscillograph. Test records of Fig. 3 show the results obtained at several sweep speeds. In Fig. 3 (a), the sudden rise of voltage appears to be almost instantaneous, and the decrease is essentially exponential except for slight irregularities due to the test arrangement. With the speed increased, the nature of the voltage rise becomes evident in Fig. 3 (b). In the final record of Fig. 3 (c), attention is directed only to a portion of the initial rise. From the nature of the record it is apparent that the simple diagram of Fig. 2 is not a true representation of the test circuit; the presence of inductance and some additional capacitance and resistance elements are necessary to account for the wave shape recorded. The duration of the fastest sweep is less than one microsecond, as evidenced by the timing wave of one megacycle recorded in Fig. 3 (c) for comparison.

Applications such as those in Figs. 2 and 3 require only a single sweep for recording. Special problems arise in coordinating the start of the sweep and the start of the phenomena to be recorded. Arrangements have been provided in the design so that this coordination can be effected in either of two ways: in one case a push button on the instrument panel initiates the sweep and also provides a simultaneous pulse at the front panel which can be used for external control; in the other case, where external control alone is desired, a pulse obtained from an external source can be applied to the oscillograph to initiate the sweep.

The second type of application is one in which a sequence of events is to be studied, with recording limited to short periods spaced more or less uniformly at a fairly low repetition rate. Such applications arise in the study of voltage breakdown in 60-cycle circuits, circuit-breaker recovery characteristics,

FIG. 1. THE TRANSIENT OSCILLOGRAPH ARRANGED FOR RECORDING
Dr. Lewis *(left)* and Mr. Nielsen



F G. 2. TEST CIRCUIT FOR SINGLE-SWEEP RECORDING

and related problems.

To provide separation of successive fast sweeps occurring with intervening time intervals, the oscillograph, in addition to having a horizontal sweep, has also been provided with a slow vertical sweep which operates in conjunction with the signal input. A slowly varying "drift" voltage applied to the vertical deflection plates has the effect of repositioning successive zero lines to lower positions for each of the fast horizontal sweeps.

An illustration of operation is provided by the test arrangement in Fig. 4, involving a type VR90 voltage-regulator tube. This type of tube, when the applied voltage reaches the "striking" potential, begins to conduct so as to maintain a nearly constant "operating" voltage throughout its normal current range. In the circuit of Fig. 4, the regulator tube is connected across an alternating voltage so that it successively fires and is extinguished each half-cycle of the 60-cycle period. The oscillograph is connected to record the current through the regulator tube. A steady-state picture of the resulting current variation is shown in Fig. 5 (a). This was taken on a separate oscillograph and indicates the phenomenon as it appears at slow speed, a long time after the circuit is energized. The sharp break and nearly vertical rise about a quarter-cycle following the beginning of each period corresponds to the time of firing. The record of Fig. 5 (b) shows the same phenomenon recorded on the "transient oscillograph." The start of the vertical sweep was begun some time before the test circuit was energized; this is evidenced by five horizontal sweeps on which no signals appear. The start of each horizontal sweep was timed to precede the actual firing; the sixth, eighth, and tenth sweeps give a clear indication of the form of the current change. It is evident that the striking potential at which the very first firing occurred differed from that of the latter two, since the change of current is displaced on the time scale. Also what appears to be a very rapid change at slow speed is actually a progressive change when viewed at high speed.

Synchronizing and timing for repetitive recording requires coordination with external control circuits. Connections are provided so that the closing of an external contact will initiate the vertical sweep. Likewise the horizontal sweeps need to be synchronized with the phenomena to be observed, and provision is made so that external pulses obtained from a peaking transformer or other pulse-forming network can be applied to the instrument for triggering.

It is evident that effects observed at one recording speed may exhibit a markedly different character at a higher speed. The new instrument may, in particular, facilitate the study of impulse breakdown occurring on the front of a surge having a steep wave front. Many opportunities also exist for the study of progressive changes and of the performance of systems which behave differently in the transient state and in the steady state. The operation of a regulator tube, which has been used here merely illustrating the performance of the oscillograph, is in itself a field of study in which there has been relatively little investigation.

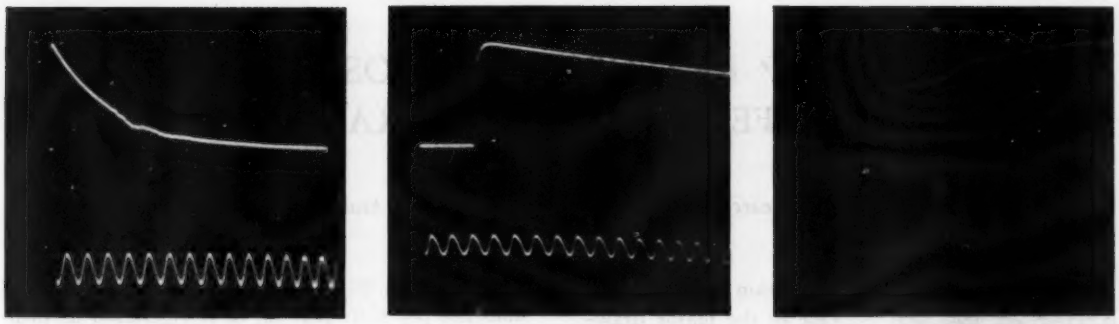
BRITISH AERODYNAMICIST VISITS ENGINEERING LABORATORIES

DURING THE FIRST WEEK in September, Dr. R. A. Frazer of the Aerodynamics Division of the National Physical Laboratory, Teddington, England, visited the Civil Engineering Department for the purpose of discussing the work of the Structural Research Laboratory on the aerodynamic stability of suspension bridges. For the past six years Dr. Frazer has been in charge of similar aerodynamic investigations relating to a proposed bridge over the Severn river in England, and a close contact has been maintained between the two laboratories.

In the fall of 1946, Prof. F. B. Farquharson, who has been in charge of the University investigation, visited the Teddington laboratories, and in 1948, Mr. G. S. Vincent, who represents the Bureau of Public Roads at the University of Washington, made a similar visit. Since the work of both laboratories is approaching conclusion it was appropriate that their joint findings be discussed.

During his visit Dr. Frazer inspected the work at the Department of Aeronautical Engineering and also spent a day with the Boeing Airplane Co. A day was also spent in Tacoma examining the new Tacoma Narrows Bridge, followed in the evening by a dinner meeting with a group of aerodynamic experts from the University and Boeing.

The fortunate coincidence of Dr. Frazer's arrival in New York with a meeting there of the Advisory Board on the Investigation of Suspension Bridges, permitted his appearance before the Board for a brief discussion of problems of mutual interest.



(a)
300-microsecond sweep
50-kc timing wave

(c)
15-microsecond sweep
1-mc timing wave

(b)
1-microsecond sweep
1-mc timing wave

FIG. 3. SINGLE-SWEEP OSCILLOGRAMS

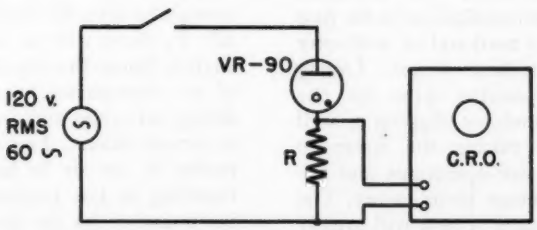
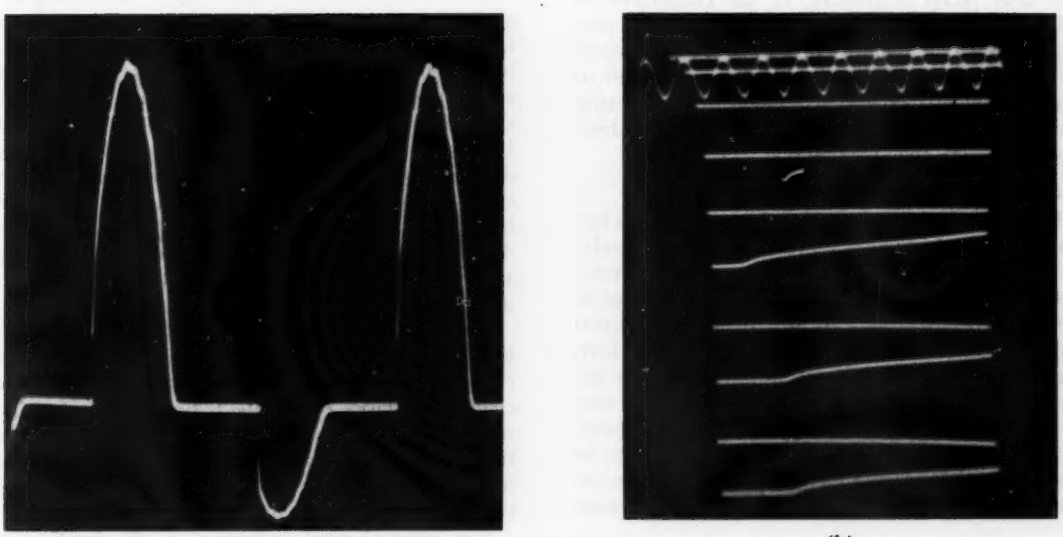


FIG. 4. TEST CIRCUIT FOR REPETITIVE SWEEPS



(a)
Steady-state record of current

(b)
Transient record of current at firing intervals
40-kc timing wave

FIG. 5. OSCILLOGRAMS OF REGULATOR-TUBE CURRENT

HEAT-PUMP EVAPORATOR FROSTING AND ITS EFFECTS ON HEAT TRANSFER*

DAVID GOLDENBERG
Research Fellow, Engineering Experiment Station

D. Goldenberg

Introduction

One of the major drawbacks to mass installation of the heat pump for residential use is its extremely high initial cost. Except for the few cases where lake or river water is available, most installations in the past have used soil or wellwater as a heat source. Laying evaporator pipe in the ground, or digging a well and raising the water to surface level are both expensive operations and are out of the question to the average home owner. The use of the outside air as a source of heat will greatly reduce initial installation costs.

One serious obstacle to overcome in using the air-to-air heat pump is frosting of the evaporator in localities where low temperatures and a high percentage of relative humidity prevail over long periods of time. It was the purpose of this investigation to determine climatic conditions under which frosting occurs most rapidly and the effect produced on heat transfer through the evaporator.

Theory

The amount of water released by the air when cooled is dependent upon the temperature and relative humidity of the original mixture and the temperature drop. For given initial conditions, the weight of moisture released per unit time is dependent upon the volume of air circulated in that time which in turn is dependent upon the rate of heat removed in the evaporator, or the "refrigerating effect." The rate that water is released by the air with initial temperature, relative humidity, and temperature drop as variables, can be expressed as pounds of moisture per ton of refrigeration in the evaporator. Typical results are plotted in Figs. 1 and 2, with the weight of moisture per hour per ton of refrigeration as ordinates and dry-bulb air temperatures as abscissae for various temperature drops and percentages of relative humidity of incoming air.

The conditions for maximum evaporator frosting will occur at outside air temperatures near the freezing point of water. With air temperatures high enough to keep the discarded air temperature above 32° F, there will be no frosting. At temperatures slightly below this the frosting problem may still be of no consequence because of automatic defrosting during off cycles and during natural climatic changes in air conditions. As the temperature drops, the capacity of the air to hold water vapor is reduced, resulting in less precipitation (and eventual frost) per pound of dry air circulated.

The amount of water deposited on the evaporator surfaces as frost or ice may differ from that shown in Figs. 1 and 2. At the beginning of the heat-pump cycle when there is no frost coating on the metal surfaces and few nuclei of ice to prevent sub-cooling, a portion of the water vapor may pass through the evaporator without coming in contact with a cold surface and thereby be discarded with the used air. Under these conditions the calculated values of frost deposit would be a maximum, with the measured values somewhat less. After the metal surfaces have been coated with frost however, the actual weight deposited may be more than the calculated quantity,* apparently because of the diffusion of water vapor inside the frost layer.

Because the thermal conductivity of frost is very low compared to that of metals used in heat exchangers, a small addition of frost on the heat exchanger surfaces will quite noticeably increase the resistance to heat transfer. To obtain exact values of the change of heat transfer for any given application, it is desirable to have experimental data for the particular type of heat exchanger design in question.

For uninterrupted operation of the heat pump under all climatic conditions, evaporator design must

*Condensed by the author from his thesis of the same title submitted for the degree of M.S. in M.E., 1951. The work was done as a part of E.E.S. Project No. 9 under the supervision of George S. Smith, Professor of Electrical Engineering.

*See "Frost Deposit Research," *Refrigerating Engineering*, May, 1949, p. 449.

provide for either an effective anti-frosting method or a method of defrosting. Fundamentally, the effectiveness of the evaporator should be as high as possible. This would not only give the highest possible refrigerant temperature for a maximum coefficient of performance, but would also achieve a low proportion of latent heat removal and eventual frost. Many other methods of preventing frost build-up are available, but their use adds to the operating costs and equipment and complicates automatic control.

Of the numerous methods suggested for defrosting, water defrosting appears to be one of the simplest and most economical to operate. A sufficient supply of water flows over the tubes to supply the latent heat of fusion necessary to melt the frost, which is then washed out through the drain. The fact that water has a constant melting point of 32° F makes it possible to defrost with tap water slightly above the freezing point. No additional supply of energy need be furnished to heat the water before using.

Test Equipment

The equipment and material used throughout the test were as follows:

1. A wind tunnel consisting of a closed passage for the continuous flow of air past the heat exchanger
2. A heat exchanger or Freon-12 evaporator
3. A scale for measuring the weight of frost added to the evaporator
4. A steam generator to replenish the air with moisture removed in the evaporator
5. A heater to supply the heat removed in the evaporator
6. Measuring and recording devices
   a) Flow meter to measure the rate of flow of freon
   b) Dew-point recorder to indicate and record the dew point of air entering the evaporator
   c) Temperature recorder for measuring temperatures of the outside air, air to the evaporator, air from the evaporator, refrigerant entering the expansion valve, refrigerant leaving the evaporator, and the room temperature
   d) Pressure gages indicating pressures throughout the refrigerating system

A sketch showing the relative positions of the wind tunnel, heat exchanger, scale, steam generator, and heater is shown in Fig. 3.

Test Procedure

Each test was run at constant dry-bulb and dew-point air-inlet temperatures, at a constant rate of flow of freon through the evaporator, and at constant evaporator pressure. The enthalpy of freon entering the evaporator remained nearly constant, any slight

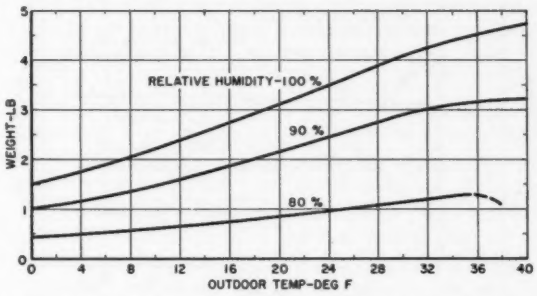


FIG. 1. Weight of moisture removed from air per hour per ton of refrigeration during a 6° F temperature drop, for various initial temperatures and percentages of relative humidity.

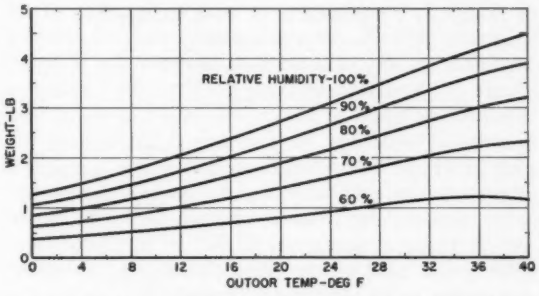


FIG. 2. Weight of moisture removed from air per hour per ton of refrigeration during a 15° F temperature drop, for various initial temperatures and percentages of relative humidity.

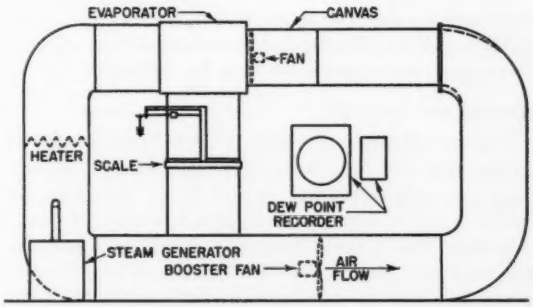


FIG. 3. ARRANGEMENT OF TEST EQUIPMENT

variation being due to the change in temperature of the air-cooled condenser. The refrigerant outlet was about 15° F superheated at the beginning of the run, the temperature decreasing as the load decreased because of frosting. This continued until the saturation temperature was reached. The change in rate of heat removal could then be related to the change in enthalpy of freon leaving the evaporator. The air-outlet temperature was such as to maintain a heat balance in the evaporator.

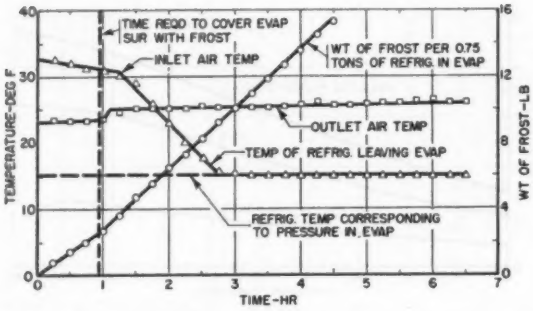

TIME REQD TO COVER EVAP SUR WITH FROST
INLET AIR TEMP
WT OF FROST PER 0.75 TONS OF REFRIG. IN EVAP
OUTLET AIR TEMP
TEMP OF REFRIG. LEAVING EVAP
REFRIG. TEMP CORRESPONDING TO PRESSURE IN EVAP
TEMPERATURE-DEG F
WT OF FROST-LB
TIME-HR

FIG. 4. Evaporator frosting rate and performance with inlet air at 35° F and 90% relative humidity.

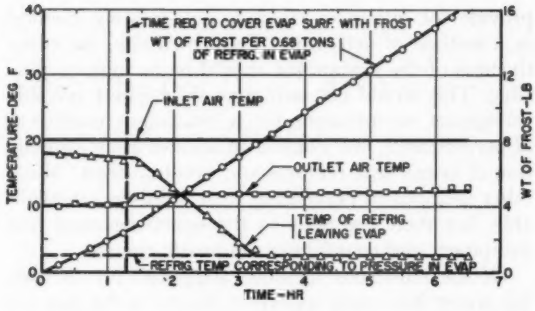

TIME REQ TO COVER EVAP SURF. WITH FROST
WT OF FROST PER 0.68 TONS OF REFRIG. IN EVAP
INLET AIR TEMP
OUTLET AIR TEMP
TEMP OF REFRIG. LEAVING EVAP
REFRIG. TEMP CORRESPONDING TO PRESSURE IN EVAP
TEMPERATURE-DEG F
WT OF FROST-LB
TIME-HR

FIG. 5. Evaporator frosting rate and performance with inlet air at 20° F and 100% relative humidity.

Each run differed from the preceding run by either a change in temperature, or relative humidity of the inlet air, or both. An attempt was made to obtain a sufficient variety of conditions to cover the complete range of temperatures from 0° F to the vicinity of the freezing point of water. The lower range of temperatures could not be maintained throughout the day as all test data were taken during late spring and early summer months when the temperature difference between the outside air and the wind tunnel would reach a maximum of 90° F for these runs. The major area of the wind tunnel was insulated, but owing to air infiltration through the canvas connections and the large temperature difference, 20° F was the lowest temperature at which suitable results could be obtained.

At the conclusion of each test the evaporator was defrosted by the use of tap water through the water defrost system. The frost removal was observed and the approximate length of time for defrosting noted.

Results and Analysis

Curves showing the rate of frost deposit on the evaporator and its effects upon evaporator performance are plotted in Figs. 4 and 5. In each case the air-inlet temperature and relative humidity remained constant. The general tendency in all cases was for the rate of frost deposit to remain constant until about 2½ lb of frost were deposited. At this time the entire area of heat transfer was coated with frost. This rate is very close to the theoretically determined rates plotted in Figs. 1 and 2, indicating that very little of the air passes through the evaporator without coming in actual contact with a cold surface. This condition was expected as the tubes were closely packed and staggered, thus creating turbulence with a high degree of random motion of the air particles. After frost had covered the last portion of the metal surfaces, the rate of frost deposit suddenly increased as was anticipated, but soon leveled off and again remained constant.

During the time that frost was collecting on the heat-transfer surfaces, the superheat temperature of the leaving refrigerant kept decreasing. With the rate of flow of freon and enthalpy at the expansion valve remaining constant, this change in superheat was the sole indication of the change in rate of heat transfer in the evaporator. As expected, the refrigerating effect decreased with time, the rate of decrease changing with the rate of frosting.

The defrosting system worked very well, with the total time to defrost being about one minute. However, with the tests run during summer months, the tap water used was much warmer than it would be during the heating season.

The test results, which were in complete agreement with the theoretical data, may be summarized as follows:

1. The frosting rate changed sharply after the heat-transfer surface of the evaporator became completely covered with a layer of frost. The frosting rate was constant before and after that time.

2. Evaporator efficiency decreased most rapidly after complete frost coverage had occurred. Before this time, the loss of efficiency was negligible.

3. Density of the first deposited layer of frost increased continuously.

Conclusions

The amount of frost required to cover the heat-transfer area is dependent upon evaporator capacity and design. Once such a value has been established for a particular evaporator design, the curves in Figs. 1 and 2 will indicate the length of time the evaporator can be in operation before complete frost coverage occurs. This should be the maximum time before defrosting, not only for maximum efficiency and to insure sufficient capacity, but to keep the frost at the lowest possible density for defrosting ease.

With the theoretical curves in Figs. 1 and 2 giving a maximum frosting rate, any deviations between

these and the actual case will provide an additional factor of safety.

The heat pump should be designed with sufficient capacity at the design temperature to provide ample "off-cycle" time for defrosting. If the lowest expected air temperature is about 38° F or higher, evaporator frosting need not be considered. With air temperatures in the vicinity of 30° F to 35° F, maximum frosting will occur, and about one hour per day should be allowed for defrosting time. At 0° F only sufficient increased capacity need be provided to care for frosting as calculated for that temperature by the use of the theoretical curves. It will be found that considerably less than one hour defrosting time is necessary since the frosting rate diminishes quite rapidly at lower temperatures. As the air temperature increases, in the case of this design, the corresponding increase in frosting rate will require more frequent defrosting periods, but the saving in operating time, which follows from the reduced heat loss and increased heating capacity, will provide a sufficient time for the increased defrosting necessary. Therefore, with proper design, evaporator frosting does not limit the use of the heat pump with air as a source of heat.

Water defrosting which has proved valuable in the refrigeration field is also a convenient and economical defrosting method for the heat pump.

ELECTRON MICROSCOPE LABORATORY PREPARES GOLD MIRRORS BY EVAPORATION

The operation of coating spherical glass surfaces with a highly reflective material was recently completed in the Electron Microscope Laboratory of the Engineering Experiment Station. The large glass pieces were for use in the infrared spectrometer under construction for the Department of Chemistry and Chemical Engineering, under supervision of Dr. E. J. Baer.

Gold was selected as the most suitable material because of its high reflectivity for infrared wave lengths and its chemical inertness to the gases to be studied. Calculators showed 1,000 Å to be the optimum thickness.

The glass pieces, one a circular split disc 9 inches in diameter and 2 inches thick, the other an 8-inch square of the same thickness, were mounted in the SC-2 high-vacuum unit, recently purchased as auxiliary shadowcasting equipment for electron microscope specimens. Under a vacuum of 10^{-4} mm of Hg, gold was evaporated from a hot tungsten filament, smoothly and uniformly coating the glass surfaces, producing highly reflective gold mirrors.

Unlike sputtered or chemically produced layers, which require further treatment, such as burnishing or polishing, for good results, layers applied in the manner described exactly reproduce the surface of the substrate.

Since these mirrors have been mounted and installed in the spectrometer, a beam of light has been reflected back and forth from one to the other for more than a hundred times, resulting in a total path length of approximately a mile in the gas to be studied.

OLIVER H. ROW
Electron Microscopist
Engineering Experiment Station

PERFORMANCE OF VAPOR-LIFT PUMP UNDER VACUUM

(Continued from page 14)

NOMENCLATURE

a = cross-sectional area of pipe, sq. feet
D = pipe diameter, feet
E = internal energy, foot lb./lb.
F = mechanical energy converted into heat by friction, foot lb./lb.
f = friction factor
g_c = gravitational conversion factor, (lb. mass) (foot)/(lb. force) (sec.^{2})
h_s = submergence measured from surface of inlet liquid to bottom of steam jacket, feet
h_l = total lift from bottom of steam jacket to vapor-liquid separator, feet
L = latent heat of vaporization, p.c.u./lb.
M = molecular weight
p = pressure, lb./sq. foot
Q = energy equivalent of heat added by external source, foot lb./lb.
s = specific heat, p.c.u./(lb.) (°C.)
T = temperature, °K.
U = over-all heat transfer coefficient, p.c.u./(hr.)(sq. ft.)(°C.)
u = velocity, feet/second
v = specific volume, cu. ft./lb.
$v_{av.}$ = average specific volume over increment of height, cu. ft./lb.
$W_{ex.}$ = external work done by fluid, foot lb./lb.
w = mass flow rate, lb./second
x = weight fraction of vapor formed
Z = height, feet
ρ_l = density of liquid entering lifter, lb./cu. foot
ρ_m = average density of mixture of liquid and vapor in rising pipe, lb./cu. foot

REFERENCES

1. SWINDIN, N., *Proc. Chem. Eng.* group **10**, 116, (1928)
2. LEWIS, W. Y., and ROBERTSON, S. A., *Proc. Inst. Mech. Engrs.* (London) **143**, 147, (1940)
3. MUKHERJEE, N. R., and PRATT, H. R. C., *Ind. Eng. Chem.* **42**, 1883, (1950)
4. BOARTS, R. M., BADGER, W. L., and MEISENBURG, S. J., *Trans. Am. Inst. Chem. Engrs.* **33**, 363, (1937); *Ind. Eng. Chem.* **29**, 912, (1937)
5. COLBURN, A. P., *Tr. Am. Inst. Ch. Eng.* **29**, 174, (1933)
6. KIRSCHBAUM, E., *Chem. Fabrik* **10**, 337, (1937)

A CHROMATOGRAPHIC STUDY OF SULFITE WASTE LIQUOR SUGARS*

P. K. MULVANY
Assistant Chemist
Pulp Mills Research

H. D. AGAR
Chief Laboratory Technician
Microbiology Department

Q. P. PENISTON
Research Chemist, Pulp Mills Research

JOSEPH L. McCARTHY
Associate Professor of Chemical Engineering

P. K. Mulvany

ABSTRACT

The sugars in a sulfite waste liquor have been recovered nearly quantitatively and free of ionic impurities by dialysis and ion exchange resin treatments of the liquor. Separation of these recovered sugars and of known sugar mixtures by partition chromatography on starch columns using a 1-butanol–water system has been studied. Behavior of the sugars investigated has been found to be in accord with a theory of chromatographic processes and relative elution rates are satisfactorily correlated with independently determined partition coefficients. The sugars present in a paper pulp sulfite waste liquor derived from 85% Western Hemlock and 15% White Fir are found to be distributed as follows: mannose, 48%; glucose, 15%; xylose, 15%; galactose, 10%; arabinose, 6%; fructose, less than 2%; unaccounted for, 4%.

H. D. Agar

Introduction

Although the nature of the several sugars present in sulfite waste liquors has been established in prior investigations,[1-4] quantitative uncertainties have remained due to difficulties of separation of all of the sugars from other sulfite waste liquor components, and to difficulties of analysis of complex sugar mixtures by classical methods. Recently we have developed new procedures for isolation of mixed sugars in high yield and purity from sulfite waste liquors using dialysis and anion exchange resins, for separation of individual sugars by partition chromatography, and for quantitative determination of individual sugars. Since these procedures apparently permit avoidance of uncertainties of earlier methods, and since they may prove useful in other wood chemistry investigations, we now report studies on known sugar mixtures and also results for the sugars present in a certain sulfite waste liquor.

Experimental

Isolation of Sugars from Sulfite Waste Liquor. A commercial paper pulp calcium sulfite waste liquor† was first exhaustively dialyzed in a continuous apparatus under conditions previously shown[5] to retain about 50% of the lignin sulfonic acids as non-dialyzable material and to yield quantitative recovery of sugars in admixture with other low molecular weight substances in the dialysate. This dialysate was concentrated at reduced pressure to about 200 g. of total solids per liter, completely deashed using Amberlite IR-100 H and then exhaustively extracted with ether.

Removal of anionic substances was accomplished by passage of the dialysate over columns (12 mm. i.d. × 30 cm.) of Duolite A-2* anion exchange resin ground and screened to 65-100 mesh and previously treated with 2% sodium hydroxide solution followed by distilled water until a neutral effluent was obtained. After addition of 5 ml. of concentrated dialysate to the column, distilled water was allowed to flow through at about 300 ml. per hour to wash the unabsorbed sugars from the resin. With 100 and 250 ml. of effluent collected in two experiments, the reducing value recovered was 87.5 and 88.5% of that present in the deashed dialysate. It is believed that this represents the fraction of the reducing value of the sulfite waste liquor associated with true sugars and that the remaining 12 or 13% is attributable to other components. Effluents from the resin columns were completely clear and colorless and showed a specific conductance at 25° of about $5.0 \times 10^{-5}\Omega^{-1}$ cm.$^{-1}$.

* Reprinted from the *Jour. Amer. Chem. Soc.*, 73, 1255 (1951). Copyright 1951 by the Amer. Chem Soc. and reprinted by permission of the copyright owners. A contribution from Pulp Mills Research, Department of Chemistry and Chemical Engineering, University of Washington.

† Kindly provided by the Puget Sound Pulp and Timber Co., Bellingham, Washington.

* Chemical Process Co., San Francisco, California.

The reducing value calculated as glucose was found to be 84% of the total solids, thus leaving about 16% as non-ionic, non-reducing material.

Chromatographic Separation of Sugars. Columns were prepared by mixing potato starch (75 g.) and Dicalite filter aid (75 g.) with 250 ml. of 1-butanol saturated with water. The solvent was removed and the cake twice again suspended in the same volume of fresh solvent. The final slurry was poured into a glass column (3.45 sq. cm. cross section) to a settled height of one meter. Butanol saturated with water was then passed through the column (0.04 to 0.05 ml. per sq. cm. per min.) for 4 days to obtain equilibrium between phases.

Q. P. Peniston

Two such columns were charged with a wet butanol solution (19.8 ml. each) containing the above-described sulfite waste liquor sugars at a concentration of 2.62 g. total sugars calculated as glucose per liter. After absorption of the sample and rinsing, the columns were attached to constant head reservoirs supplying wet butanol and samples, each consisting of the eluant over a 2-hour period, were collected automatically.

Using substantially identical procedures, chromatographic separations were also conducted in duplicate on known mixtures of xylose, mannose, glucose and galactose.

Eluant samples were analyzed for total reducing sugars by the Shaffer-Somogyi method[6] using a 0.65-ml. aliquot measured with a calibrated micro pipet.

Results and Discussion

For nearly quantitative recovery of sulfite waste liquor sugars substantially uncontaminated by lignin sulfonates and other cations or anions, removal of high molecular weight lignin sulfonates by exhaustive dialysis is desirable since these substances are not readily absorbed by the subsequent anion exchange resin treatment. The alternative removal of these substances by precipitation as heavy metal or amine salts seems more likely to cause sugar loss or destruction. Ether extraction of the concentrated deashed dialyzate serves to remove resins, fatty acids, and other substances which might not be retained by the anion resin. This extraction may not be necessary to the success of the chromatographic separation of sugars. No characterization has yet been made of the non-reducing material present to the extent of about 16% in the purified sugar fractions.

J. L. McCarthy

The chromatographic elution curves obtained for known sugar mixtures and for sulfite waste liquor sugars are shown in Fig. 1. Identification of the sugars giving rise to peaks in the elution curves was confirmed by consideration of their characteristic elution rates as controlled by their respective partition coefficients between butanol and water and by the phase volume ratio in the chromatographic columns.[7]

Partition coefficients for the five principal sugars of sulfite waste liquor were determined at 25° as shown in Table I for the system butanol–water when about 6.7 g. of sugar was present per liter of aqueous phase. These experimental partition coefficients are found to be in satisfactory relation with R_F values (ratios of solute to solvent migration distances) determined by Partridge and Westfall[8] for partition chromatography on filter paper strips using the same system in the presence of a little ammonia. Thus using the expression of Consden and co-workers,[9]

$$K = \frac{AL}{A_s}\left(\frac{1}{R_F} - 1\right)$$

where AL/A_s is the ratio of areas of mobile and immobile phases, the experimental values of K and of R_F for glucose were substituted to compute the

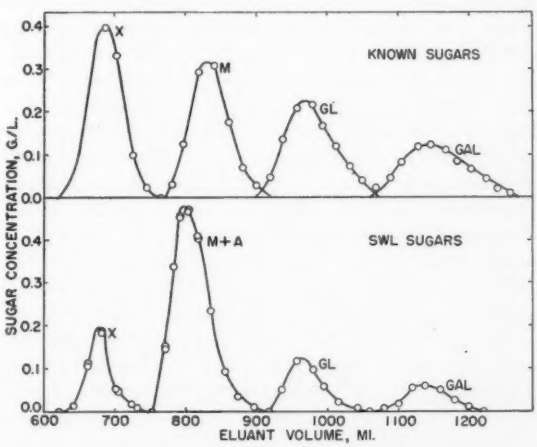


FIG. 1. CHROMATOGRAPHIC ELUTION CURVES FOR SUGARS
(X, M, A, Gl, and Gal designate xylose, mannose, arabinose, glucose, and galactose, respectively.)
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TABLE I

PARTITION COEFFICIENTS OF SUGARS

Sugar	$K_{expt.}$[a]	R_F[b]	$K_{calcd.}$[a,c]
Xylose	17.1	0.125	16.0
Arabinose	21.5	.100	20.6
Mannose	21.6	.100	20.6
Glucose	30.5	.070	Ref.
Galactose	36.2	.060	36.0

[a] K = grams sugar per liter of water phase/grams sugar per liter of butanol phase. [b] R_F values reported by Partridge and Westfall.[8] [c] Computed from R_F values shown referred to glucose.

TABLE II

RATIOS BETWEEN PARTITION COEFFICIENTS AND BETWEEN ELUANT VOLUMES AT MAXIMUM SOLUTE CONCENTRATIONS

Sugar	(K_{sugar}/ $K_{galactose}$)	(Eluant volume sugar/ eluant volume galactose)	
		Known mixture	SWL sugars
Xylose	0.47*	0.61	0.59
Mannose	.60*	.73	.71[a]
Glucose	.84	.84	.85
Galactose	1.00	1.00	1.00

*Corrected by the authors after original publication.
[a] Mannose in eluant is here accompanied by arabinose and possibly fructose.

area ratio and then values for K were calculated for other sugars from Partridge's R_F data with results shown in Table I.

From Mayer and Tompkins' treatment of the chromatographic process,[7] it may be shown that the ratios of partition coefficients for solutes should be equal to the ratios of respective effluent volumes to the maximum concentration of the effluent. Such ratios referred to galactose are shown in Table II for xylose, mannose and glucose. These were calculated from the experimental partition coefficients and also from the experimental volumes of column effluents to elution peaks for both known sugar mixtures and for sulfite waste liquor sugars. The close agreement among these ratios together with chemical characterization of xylose as the cadmium brom xylonate,[10] confirms the identity of the individual sugars eluted from the known mixture. The recoveries of the sugars from known mixtures in duplicate experiments are shown in Table III.

For the sulfite waste liquor sugars, xylose, glucose and galactose were identified as indicated above. However, the partition coefficients of mannose, arabinose and fructose are nearly identical so that these substances were eluted together. Thus the amounts of arabinose accompanying mannose were determined in appropriate eluant fractions by a new empirically-standardized micro procedure[11] involving determination of ultraviolet absorption of dilute acidified sugar solution heated for fixed periods of time. Since the rate of furfural formation from arabinose is much greater than that of hydroxymethylfurfural from mannose, a high degree of sensitivity is achieved. The presence of fructose accompanying mannose was indicated by polarographic examination,[12] but the sensitivity of the procedure permitted only the definition of an upper limit for the amount of fructose possibly present.

TABLE III

RECOVERY OF SUGARS FROM KNOWN MIXTURES

Sugar	Amount added per column, mg.	Amt. recovered, mg.		Recovered, %	
		Column A	Column B	Column A	Column B
Xylose	18.59	20.12	21.68	108	116[a]
Mannose	19.27	20.80	20.48	108	104
Glucose	18.51	19.04	19.32	103	104
Galactose	15.70	14.00	14.56	89	93
Other[b]	.....	0.47	0.18	0.6	0.2
Total	72.07	74.43	76.22	103	106

[a] High recovery is probably due to summation of small errors in sugar analyses. [b] Recovered in wash water used finally to purge the column.

TABLE IV

COMPOSITION OF SULFITE WASTE LIQUOR SUGARS

Sugar	85% Western Hemlock + 15% White Fir Wood,[a] %	Spruce,[b] %
Xylose	15	17.0
Arabinose	6	
Mannose	48	42.7
Fructose	< 2	4.0
Glucose	15	28.9
Galactose	10	4.2
Galacturonic acid	[c]	3.2
Unidentified	4	....
Total	100	100

[a] Average of two determinations of present study. [b] Undesignated species.[4] [c] Not investigated in present work.

In Table IV are shown the proportions of the several sugars found present in the sulfite waste liquor sample derived from about 85% Western Hemlock (*Tsuga heterophylla*) and 15% White Fir (*Abies grandis*) woods.* This sulfite waste liquor contains relatively less glucose and more galactose than a sulfite waste liquor from a spruce which was examined by Hägglund[4] with results also included in Table IV. Total reducing value recoveries in present chromatographic experiments were 95 and 101%.

*Kindly provided by the Puget Sound Pulp and Timber Co., Bellingham, Washington.

REFERENCES

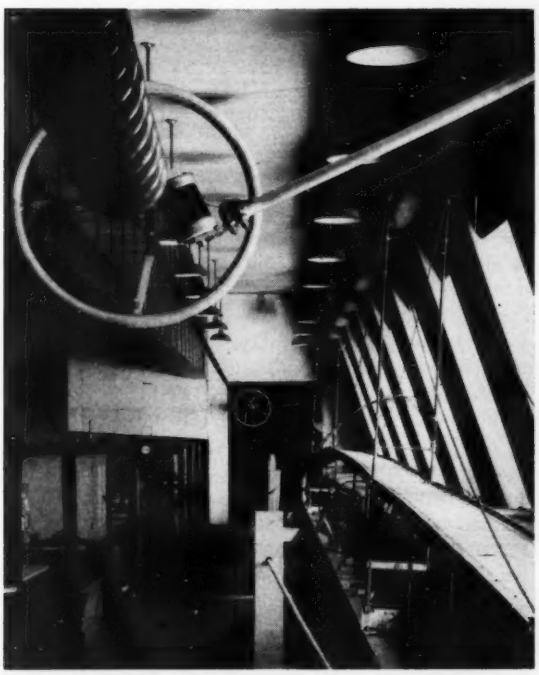
1. H. Krause, Chem. Ind. (Berlin) *Nachr.-Ausgabe*, **29**, 217 (1906).
2. E. Hagglund, *Biochem. Z.*, **70**, 416 (1915).
3. P. Klason, "Kempe-Festschrift von Skogsvårdsföreningens Tidskrift," Stockholm, 1917, p. 224.
4. E. Hagglund, F. W. Klingstedt, T Rosenquist and H. Urban, *Z. Physiol. Chem.*, 177, 248 (1928).
5. Q. P. Peniston and J. L. McCarthy, *Jour. Amer. Chem. Soc.*, **70**, 1324 (1948).
6. Shaffer and Somogyi, *J. Biol. Chem.*, **100**, 695 (1933).
7. Mayer and Tompkins, *Jour. Amer. Chem. Soc.*, **69**, 2866 (1947).
8. S. M. Partridge and R. G. Westfall, *Biochem. J.*, **42**, 238 (1948).
9. R. Consden, A. H. Gordon and Martin, *ibid.*, **38**, 224 (1944).
10. A. W. Van der Haar, "Anleitung zum Nachweis zur trennung und Bestimmung der Monosaccharide und Aldehydsäuren," Borntraeger, Berlin, 1920, p. 59.
11. Q. P. Peniston and H. D. Agar, unpublished work.
12. J. Heyrovsky and I. Smoler, *Collection Czechoslov. Chem. Commun.*, **4**, 521 (1932).

NOTE

Since publication of this paper, a new method of correlation of eluate volumes to maximum concentration of a solute and the partition coefficient of the solute has been developed. This method has been reported in a note to the *Journal of the American Chemical Society*. The Authors.

Bonneville Power-Line Radio Interference Tested in Wind Tunnel

The extent of radio static caused by power lines when they are whipped by the wind is being investigated in a cooperative research project sponsored by the Bonneville Power Administration. Cooperating with BPA engineers are Prof. G. S. Smith and Instructor A. B. Jacobsen, of the Department of Electrical Engineering. Tests are being made at the Suspension Bridge Laboratory wind tunnel on the campus.



Power Cable Mounted in Wind-Tunnel Jet

The project is part of the Bonneville Power Administration's continuing study of various factors affecting power-line interference on radio reception. Such interference is caused when, owing to high voltage gradients, corona is formed on the conductor, resulting in a current flow which generates broadband radiated energy. Field data on actual transmission lines have indicated that interference increases with wind velocity.

A 10-ton metering transformer, 16 feet high, (see front cover) was shipped to the campus from a BPA substation near Eugene, Oregon. To check the amount of the increased static, a 92-foot power-line section has been erected in the wind tunnel. (See accompanying photograph.) Electrical voltage, ranging from 20,000 to 175,000, is being applied to the power line while winds of velocities varying up to 18 mph are developed in the tunnel. The effects of smoke and dust with wind are also being investigated. Smoke is generated by burning green brush in a garbage can; this operation requires gas masks for the test crew. Dust is prepared by sieving dry dirt to the desired size and dusting it on the conductor. The test span in the wind tunnel is supported under tension between two 8-foot strings of insulators. A noise meter checks the amount of interference. Several sizes of conductors are to be tested, those for projected lines of 287 kilovolts, and for present lines of 220 kilovolts and 110 kilovolts. Additional field data have been taken to try to determine factors which may cause a difference between laboratory and field results.

As yet no statement can be made as to the effects of wind on radio noise. Results of the tests when completed will be published by the University Engineering Experiment Station.

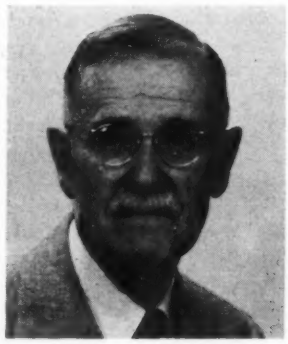
IOWA BRIDGE TESTS REVEAL PERSISTENT CONCRETE-STEEL BOND*

ALMON H. FULLER
Professor of Civil Engineering, Iowa State College

ALMON HOMER FULLER came to the University of Washington in 1898 as Professor of Civil Engineering (and sole member of the engineering faculty) and the following year was appointed Dean of the College of Engineering. When he left in 1917 the staff had grown to 35 members. During the interim, in addition to administrative and teaching duties, he conducted research in testing materials, with the late Professor C. C. More as collaborator on the most notable project results of which were published in 1917 under the title, "Time Tests of Concrete," in the *Proceedings* of the A.C.I. In 1907 he served as president of the Pacific Northwest Society of Engineers, and from 1911 to 1913 he was a member of the committee to revise the Seattle Building Code. From the University of Washington, Professor Fuller returned to his alma mater, Lafayette College (C.E., 1897; M.S., 1900; Sc.D., 1936), as Professor of Civil Engineering. In 1920 he went to Iowa State College as Professor of Civil Engineering and served as head of the department until 1938. From 1920 to 1925 he was consulting bridge engineer for the Iowa State Highway Commission, and from 1922 to 1929 was chairman of the ASCE Special Committee on Impact in Highway Bridges. In addition to numerous publications in periodicals, Professor Fuller was co-author, with Frank Kerekes, of *Analysis and Design of Steel Structures* (Van Nostrand Co. rev. ed. 1936).

IMPACT TESTS made on the Skunk River Bridge in 1922-1925 gave evidence of composite action between the stringers and the reinforced concrete floor slab. This evidence was generally accepted, but there was doubt as to how long such composite action would continue under service conditions. The bridge was then new, having been opened to traffic in 1921. . . .

When in 1948 the bridge was declared inadequate for modern traffic, largely because of clearances, and was slated to be moved to another location on a secondary road, an opportunity was presented to make a brief exploratory investigation on the bridge to determine whether there was still evidence of composite action between stringers and floor slab.



A. H. Fuller

The 1922-1925 investigations included tests on two sections of the bridge, the west panel of the truss span and the west approach span (Fig. 1). These same two sections were chosen for the 1948 tests. . . .

Stresses computed from deflections when the steel alone was considered to carry the load were less than those computed from the strains, and stresses based on full composite action were greater than those from the strains. For the approach span the differences were not great, and the two sets of stresses from deflection may be considered as the limits of a band within which the actual stresses lie. For the west panel, the deflection stresses for steel alone were reasonably close to those from strains, while those computed on the assumption of full composite action were very much greater.

The ratio of the load transferred to the maximum stressed stringer to the total load was determined as the unit stress in the one stringer compared with the sum of the unit stresses in all the stringers. For the 1948 tests, these ratios were 0.18 and 0.19 with the load on the side of the roadway, and 0.15 and 0.17 with the load on the center line. The 1925 results were from 0.23 to 0.25 for the load on the side, and 0.17 and 0.19 for the load on the center line. The value computed from the specifications is 0.21. Thus in 1925 the load on the maximum stressed stringer was greater than that allowed by the specifications, and in 1948 it was less. The differences may be attributed to at least two factors—difference in type of trucks for loading, and difference in the thickness of the concrete floor, which was 6 in. in 1925 and 9 in. in 1948. . . .

It should be mentioned that visual observation showed the concrete around the top flange of the I-beams on the approach span to be sound, whereas it was broken in many places on the west panel.

These tests were subject to the same limitation as most previous ones—inability to secure, or to move over the highways, a load sufficiently great to develop

*Reprinted in slightly abridged form from July, 1951, issue of *Civil Engineering*, published and copyrighted by the American Society of Civil Engineers.

full unit stresses in the structure. Within the limits of the available live load, the results indicate that the stress in the steel stringers in each span was decidedly less than would have been developed in the steel acting alone as simple beams. Although no mechanical bond had been provided, the reinforced concrete floor evidently contributed in some manner.

In the approach span the evidence points to definite (if not full) composite action even though the span had been in use for 28 years under heavy traffic. In the west panel the measured strains and deflections and the slight cracking of concrete around the flanges of the stringers indicate but little direct action between concrete and steel. Yet the low stresses in the stringers suggest that they are getting help. The resisting moment from the steel reinforcement in the floor slab and from the stringer to floor-beam connections could provide about the necessary amount of help.

Although these deductions may reflect correctly the small unit stresses developed by the available live load, no information is available for extending the results to fully loaded structures. No general conclusions should be drawn from an exploratory research as brief as this, but it may serve as a basis for further discussion and research. . . .

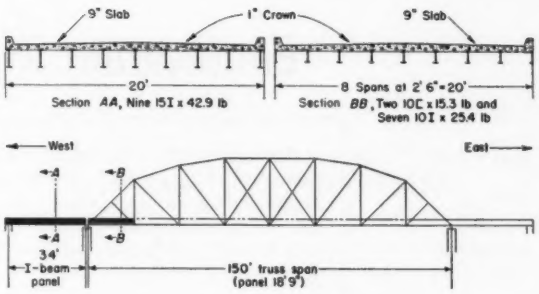


FIG. 1. Elevation and cross sections of Skunk River Bridge, on Lincoln Highway near Ames, Iowa, show main features of design. Reinforced concrete floor, originally 6 in. thick, was increased to 9 in. in 1929. No mechanical bond was provided but concrete extends a little under top flange, about 1 in. below top of steel. Sections tested both in 1922-25 and in 1948 are shown in heavy lines.

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CAN RELIANCE BE PLACED ON NATURAL CONCRETE-STEEL BOND?*

E. W. BLUMENSCHEIN

Bridge Engineer, Iowa State Highway Commission, Ames, Iowa

. . . THE LITERATURE abounds in examples of composite beam action, some with and some without mechanical anchorage. There is, however, a dearth of published reports in this country on bond behavior in composite sections after a period of service. Professor Fuller's 1948 tests fill a great need. . . .

Especially interesting is the marked difference in the behavior of the approach span and the floor of the west panel of the truss span. All the evidence indicates that there is still perfect bond between beam and slab and true composite action on the approach span. The computed bottom-flange stress, assuming composite action, is given . . . as 4,900 psi, while the observed or measured stress is 3,500 psi. Is this discrepancy excessive? I believe not. If the computations had been based on more realistic specifications, the computed stress would be much nearer the observed stress. . . . The concrete curb, being attached to the floor slab and acting as a monolith with it, has an appreciable stiffening effect.

Again, the observed stress in the top flange is zero, which is in close accord, for full composite action, with the neutral axis for live loads near the junction of slab and beam flange. Furthermore, there is no visible evidence of slip along the junction line.

In the truss panel, the behavior of the floor slab definitely indicates bond failure between the slab and the beam flange. Here the supporting beams are only 10 in. deep instead of 15 in. as on the approach span. For complete composite action, the neutral axis would fall about 2½ in. *above* the bottom of the slab, and under live load the entire beam would be in tension. The observed stresses, however, show a tension of 6,200 psi in the bottom flange and a *compression* of 4,900 psi in the top flange. The inference is that there has been total bond failure. The partial composite action indicated by the smaller observed stress in the top flange than in the bottom flange can readily be explained by the frictional resistance of the gritty slab sliding on the top beam flange. The observed flange stresses place the neutral axis about ½ in. above the center line of the beam—a long drop from its initial position up in the slab 1½ in. above top of beam.

Why should there be bond failure in the main truss span and not in the approach span? In looking for the answer to this question it is hardly necessary to go beyond Professor Fuller's report and the difference in the design of the two spans. The horizontal shear at the end of the approach span is reported as 90 psi over the top flange area, and this shear of course diminishes toward the center of the span. Assuming a safe design bond value of 100 psi for concrete deposited against a fairly smooth steel surface under favorable conditions, the design is conservative. The particularly favorable condition in this case is the concrete end diaphragm 15 in. in horizontal dimension, which was placed monolithically with the floor slab, filling the space between the beams down to the bridge seat. This end block forms an extra anchorage for the end of the beam and effectively prevents curling of the slab.

On the main truss, conditions are different. The reported computed horizontal shear, or bond value between steel

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Engineering Research Dividends

Recent theses for advanced degrees, which were submitted as reports on Engineering Experiment Station research projects, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station.

HOLMES, W. H., "The Adsorption of Binary Hydrocarbon Mixtures on Activated Charcoal." M.S. in Chemical Engineering, 1951.

The adsorption of hydrocarbon gases on activated charcoal is an important separation process in modern petroleum refining. Most of the fundamental work in this field has been concerned with equilibrium adsorption values for pure gases. The work reported here deals with mixtures of gases and with rates of approach to equilibrium. Both of these topics are of primary importance to the design and construction of a commercial scale adsorption plant. The systems studied were butane-propane, butane-propylene, butane-ethylene, propane-ethylene, and propylene-ethylene. For the above named systems equilibrium data and rates of adsorption were determined at 25° C and at two pressures: approximately 0.36 and 0.78 atmospheres. These data were then correlated by means of an empirical formula. It was found that the lighter component of the mixture was adsorbed rapidly at first and that it was later replaced to a greater or less degree by the heavier component. This rate of approach to equilibrium was found to be exceedingly rapid in most cases.

KENWORTHY, K. J., A Determination of Strain Energy Distribution and True Stresses in the Plastic Range in a Notched Steel Plate." M.S. in Civil Engineering, 1951.

The strain energy distribution and the axial true stress distribution were computed in the plastic range of the material from the test data for a steel plate with a centrally located opening that was square with rounded corners. The test was made at room temperature. The octahedral theory was used for the determination of the strain energy absorption, while the true stresses were computed by the use of a method which was developed in the course of the research of which this investigation was a part. The unit strain energy distribution was determined for loads of 500, 650, 720, and 800 kips. These loads ranged from 63 per cent to 100 per cent of the maximum load. The values of the total strain energy absorption for each load were computed from the grid measurements and compared with the values of the total strain energy absorption as determined by the areas under the load-average elongation curve for the respective loads. This comparison showed that the error was about 30 per cent for the 500-kip load, 20 per cent for the maximum load of 800 kips, and about 10 per cent for the loads of 650 and 720 kips. The axial true stress distribution was computed on four transverse cross sections for the maximum load of 800 kips. The total load on each cross section was calculated from the computed true stresses and the measured thickness. These calculated values of the total load ranged in error from 1 per cent to 6 per cent when compared with the testing machine load. Both the octahedral theory and the method used for the determination of true stress appear to be applicable in the plastic range of structural steel. While precise results were not realized in this investigation, it is believed that, with a few refinements in the experimental method, more accurate and dependable results could be obtained.

LOEB, L. M., "Load Characteristics and Distribution Problems of Electric Space Heating in Seattle." M.S. in Electrical Engineering, 1947.

The investigation reported in this thesis undertook to analyze demand characteristics, to study an existing distribution system with regard to its capacity for heating loads, and to consider the economics of this type of load under present rate schedules. Most of the data were obtained from records of the Department of Lighting of the City of Seattle. Heating-load data came from 33 recently constructed all-electric homes of similar size and construction and with complete insulation. Electric space heating is compared in cost with oil heating at 70 per cent efficiency and

(Continued on page 32)

Notes and Comments

ENGINEERS IN THE NEWS

Two fellowships, each carrying a stipend of $2,000 for one year, have recently been granted to the University for research in chemical engineering. **TAPPI** is sponsoring a study of the use of waste products of the pulp industry, such as lignin. Research under the fellowship grant of the **HOOKER ELECTROCHEMICAL COMPANY** will be concerned with use of products of the electrochemical industry in the Pacific Northwest. No research fellows have as yet been assigned to these projects.

R. A. HECHTMAN, Associate Professor of Structural Research, is co-author, with Wilbur M. Wilson and W. H. Bruckner, of Bulletin No. 388 recently published by the Engineering Experiment Station of the University of Illinois. The bulletin, 96 pages, is entitled "Cleavage Fractures of Ship Plates," and reports work done by Dr. Hechtman at the University of Illinois.

H. M. RUSTEBAKKE, Assistant Professor of Electrical Engineering, presented his paper, "Transmission-Line Terminal-Voltage-Ratio for Best Economy," before the Pacific General Meeting of the AIEE in Portland, August 22. This is the paper which earlier won the first prize award for the Ninth District of the AIEE.

J. L. McCARTHY, Associate Professor of Chemical Engineering, attended the meeting of the International Congress of Pure and Applied Chemistry in New York where, on September 12, he read a paper entitled "Lignin IV: Fractional Solution of Barium Lignin Sulfonates by Ethanol-Water Mixtures," with **G. F. FELICETTA,** Assistant Chemist, Pulp Mills Research, and **Q. P. PENISTON,** Research Chemist, Pulp Mills Research, as co-authors. Dr. McCarthy also presided at the Wood-Chemistry Symposium at the meeting of the American Chemical Society September 5. Chemists from Germany, Canada, and Sweden took part in the symposium.

September 27-28 at Bagley Hall, the Pacific Section of **TAPPI,** held its Fifth Annual Seminar on the Mechanical Properties of Paper. **Dr. BORJE STEENBERG,** Director of Research, Paper Technology Department, of the Swedish Forest Products Research Laboratory at Stockholm, gave four lectures, as follows: I, "Introduction;" II, "Mechanical Properties of Single Fibers and Paper;" III, "Paper as Viscoelastic Material;" IV, "Applications."

ENVIRONMENTAL RESEARCH SERVICE OFFERED TO INDUSTRIES

The Environment Research Laboratory, a cooperative University agency established for service to industries and cities in meeting their problems of industrial hygiene and air pollution, has now been functioning for about a year. The Laboratory is administered by a committee representing the Engineering Experiment Station (Prof. F. B. Farquharson), the Department of Public Health and Medicine (Dr. L. E. Powers), the Department of Meteorology and Climatology (Dr. Phil E. Church), and the Sanitary Engineering Division of the Civil Engineering Department (Prof. R. G. Tyler).

The operating staff now includes Dr. J. Leon Sealey, medical consultant; Mario Storlazzi, industrial hygiene chemist; A. S. Gorai, industrial hygienist; Ross N. Kusian, mechanical engineer; and T. A. Hill, meteorologist. In addition, a research program, employing graduate students, is under way.

The Laboratory is prepared to help industries solve health problems by determining the extent of existing hazards and by recommending methods of control. It also offers air-pollution studies and consultation services to communities. Since the organization has no financial assistance from the state, the industries and cities using the service will sponsor their individual projects.

Already in operation are projects concerning safeguards to be used in handling organic phosphate sprays, air pollution in Seattle, handling of fungicides, and the effects of rocket exhaust gases on human beings.

STATE COUNCIL ON HIGHWAY RESEARCH ASSIGNS CLASSIFICATION PROJECT

Professor R. G. Hennes of the Department of Civil Engineering, representing the University of Washington, was elected chairman of the Washington State Council on Highway Research at a meeting in Olympia, September 13. The other members of the Council, also appointed by Governor Langlie last June, are W. A. Bugge, Director of Highways, John E. Maley of the State Highway Commission, R. C. Watts of the Association of County Commissioners, C. W. Martin of the Association of Washington Cities, and Professor E. B. Moore of the State College of Washington.

The purpose of the State Council on Highway Research is to augment, correlate, and classify all highway research resources in the State of Washington for the solution of the state highway transportation problems. To this end, maximum use will be made of the research facilities of the University of Washington, State College of Washington, the counties, cities, state highway department, and any other group which has facilities to bring to bear on the economical solution of this state's many problems involving highways, roads and streets.

The Council will consider for assignment to an appropriate agency any problem presented to it by the legislature, highway-user group or any other representative body which has problems in the field of highways, roads or streets.

At the request of the Legislature, the Council has delegated a study of highway classification to the University of Washington and the State College. Several other proposals are under consideration.

Can Reliance Be Placed on Natural Concrete-Steel Bond?

(Continued from page 29)

flange and concrete, for composite action, is 300 psi. This is far above our assumed safe value of 100 psi for favorable conditions. . . .

In addition to the excessive bond stress, there is no redeeming end anchorage as on the approach span, and in consequence slab curling or humping will contribute to the early and progressive bond failure. . . .

It is believed that the condition of the west panel of the main span is not representative of the structure as a whole. There may be three reasons why this is so:

1. The severe impact tests with solid rubber tires passing over obstructions, which were conducted on the bridge in 1922-1925, were confined to this panel.
2. The roughness of the floor expansion plates at this end of the span produce greater impact than at any other place on the span.
3. A visual inspection shows the concrete to be in much better condition in all the other panels of the main span.

If the 1948 tests had been conducted on any other panel except this one it is likely that they would have shown considerable composite action, although there are indications that bond failure near the end of the stringers is developing throughout.

Speaking from the designer's point of view, it seems safe under favorable conditions to assume full composite action even though no formal mechanical shear developers are used. The important conditions to be met seem to be:

1. Keep bond stresses low, probably not over 100 psi.
2. Provide details to prevent curling or humping of slab, particularly at points of maximum shear. End diaphragms cast monolithically with the floor seem very effective. For long spans similar intermediate diaphragms might be considered.
3. When in doubt, use mechanical shear developers. These devices should be designed to prevent uplift of the slab such as occurs with curling.

In conclusion, the immediate practical benefits to be derived from this 25-year check-up on a patient still in the prime of life so far as giving service is concerned, should be stressed. There are literally hundreds of simple I-beam spans with concrete floors scattered over the State of Iowa, all very similar to the approach span of the Skunk River Bridge. Spans of this type can readily be widened if they meet load requirements, and a competent visual inspection will reveal whether there is still full composite action. For such patients, retirement should still be far in the future.

For types other than simple beam spans now in service, the determination of whether there is composite action becomes more difficult. Visual inspection is still the first tool. In doubtful cases, strain-gage measurements of top and bottom beam-flange stresses under a known heavy live load would give a valuable check. . . .

Steam Plants and the Northwest Power Shortage

(Continued from page 9)

8. *Federal Power Commission Proceedings,* Project No. 2016, Exhibit No. 26 (Robbins, Floyd D.), November, 1950. Vols. 9 and 10.
9. "Steam-Electric Plant Construction Cost and Annual Production Expenses," Federal Power Commission, F.P.C. S-72, 1938-1947.
10. *Ibid.,* F.P.C. S-74 (1948).
11. *Ibid.,* F.P.C. S-83 (1949).
12. "Sixth Steam Station Cost Survey," *Electrical World,* Vol. 133, No. 17, April 24, 1950.
13. Houston, Holland H., "The Place of Steam-Electric Generating Stations in the Orderly Program of Electric Power Development in the Pacific Northwest," Bulletin No. 38, Department of Conservation and Development, State of Washington, August, 1950.
14. Federal Power Commission, Project No. 2016, Statement of George A. Kendall (W. C. Gilman and Co., Engineers), November, 1950.
15. "Review Report on the Columbia River and Its Tributaries," Corps of Engineers, Department of the Army, 1948, Appendix O, pp. 0-191.

Problems of Electric Space Heating in Seattle

(Continued from page 30)

coal heating at 40 to 50 per cent efficiency. The heating load added to the present load may bring about a complete change in the load characteristics and necessitate changes in the distribution system. Few, if any, atemtpts have been made so far to change the power rates to fit this new load. Rather there is a tendency to fit the heating loads into the "all-electric" rate. To compensate for the low yearly load factor the energy rates for electric heating are to be raised sharply. Consequently electric heating will be removed from its competitive position with combustible fuel heating. In addition it will make consumers more conscious of their heating needs, causing them to restrict heating to shorter periods of greater intensity, and thereby increasing the demand factor and decreasing the yearly load factor. A monthly minimum rate combined with low energy rates, on the other hand, will guarantee compensation for the low yearly load factor, will encourage freer use of heating (possibly continuous night heating) and thereby reduce high demands and increase the yearly load factor. The present "all-electric" rate specifies the type of water-heating equipment acceptable. There is no reason why a residential "all-electric" and heating rate should not similarly entail restrictions regarding types of heating plants and their system of control, eliminating auxiliary heat from any benefits given to consumers entirely dependent upon electricity for their heat. "All-electric" rates may not be adequate when applied to present systems at present costs, but neither are many portions of the present systems able to carry electric heating loads. Rates for electric heating should therefore be based on the probably lower costs per kilowatt delivered of a system with a capacity several times that of the present one.

PUBLICATIONS

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Requests for copies of publications should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

BULLETINS

48. The Influence of Pipe Thickness on Re-Entrant Intake Losses. Charles William Harris. 35 pp. 1928.
55. Vacuum-Tube Control for Electric Wind-Tunnel Balances. Fred Scoville Eastman. 20 pp. 1931.
56. Constant Flow Characteristic of the Plane Orifice in Proximity to Side Walls. Charles William Harris. 18 pp. 1931.
58. Preliminary Tests of Thirteen Washington Coals in a Powdered Coal Boiler Plant at the University of Washington. George Samuel Wilson, Harry Fagan Yancey, and Joseph Daniels. 27 pp. 1931.
60. An Electromagnetic Balance for Force Measurement of Current Control. Fred Scoville Eastman, 29 pp. 1932.
61. Hydraulic Flow Characteristics of a Square-Edged Intake. Charles William Harris. 21 pp. 1932.
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116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part III, The Investigation of Models of the Original Tacoma Narrows Bridge Under the Action of Wind. F. B. Farquharson. (In preparation.)
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119. The Extremum Principles of the Mathematical Theory of Elasticity and Their Use in Stress Analysis. (The Walker-Ames lectures of the Spring Quarter, 1950.) W. Prager (Brown University). 30 pp. 1951. Price: 75 cents.

REPORTS

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S. Sergev